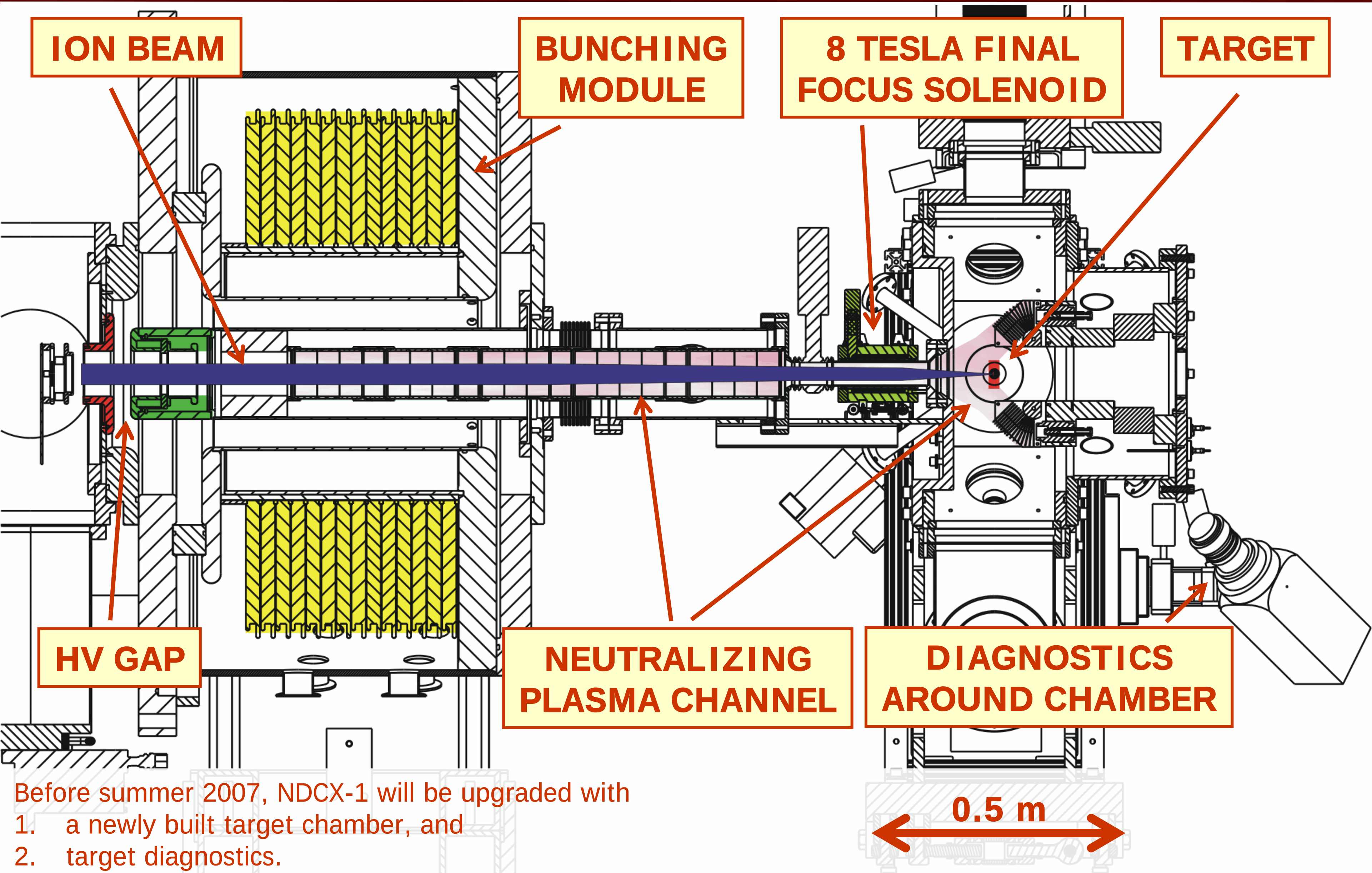
NDCX-2

WDM DRIVER PLANNING IN THE HIFS-VNL

INFORMATION PACKAGE FOR PAC, FEBRUARY 2007

TABLE OF CONTENTS:

TARGET CHAMBER AND FINAL FOCUS MAGNET WILL BE ADDED TO NDCX-1 IN SPRING 2007



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1. a newly built target chamber, and
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(LSP simulation by A. Sefkow)

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BUT acceleration is still missing for >1 eV uniform heating!

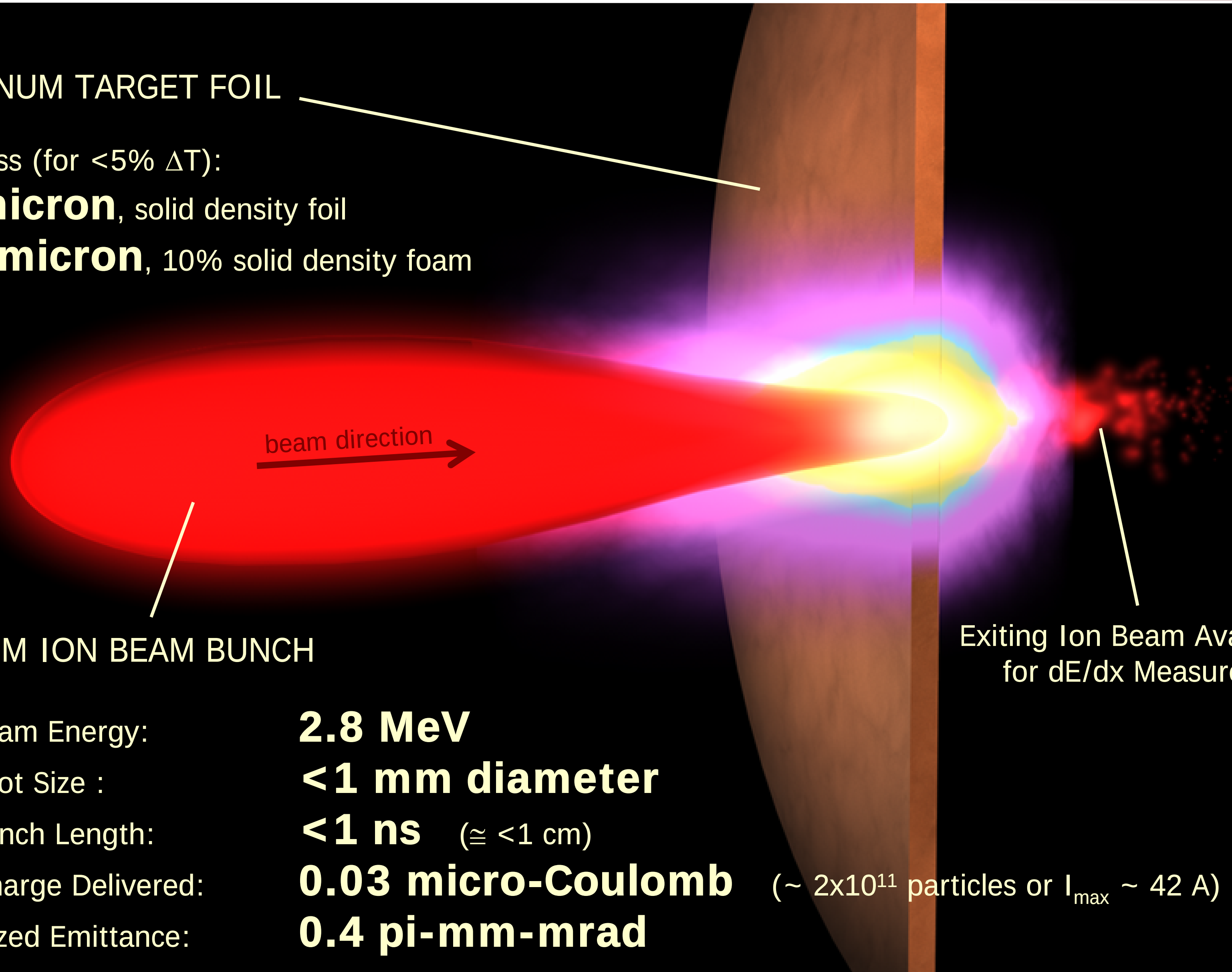
NDCX-2 TARGET POINT DESIGN AND DRIVER REQUIREMENTS FOR >1 eV TARGET HEATING

ALUMINUM TARGET FOIL

Thickness (for <5% ΔT):

~3 micron, solid density foil

~25 micron, 10% solid density foam

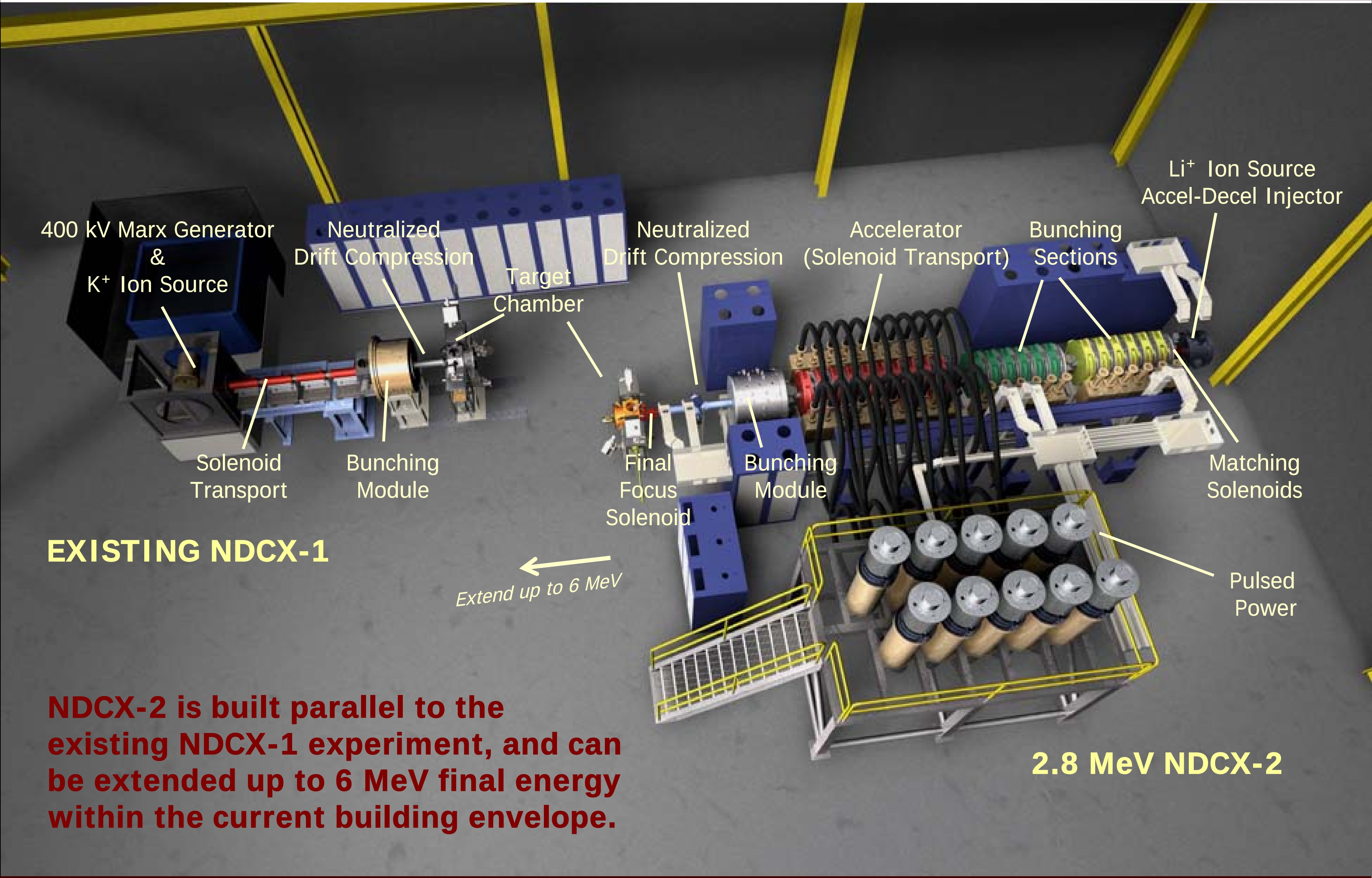


LITHIUM ION BEAM BUNCH

Exiting Ion Beam Available for dE/dx Measurement

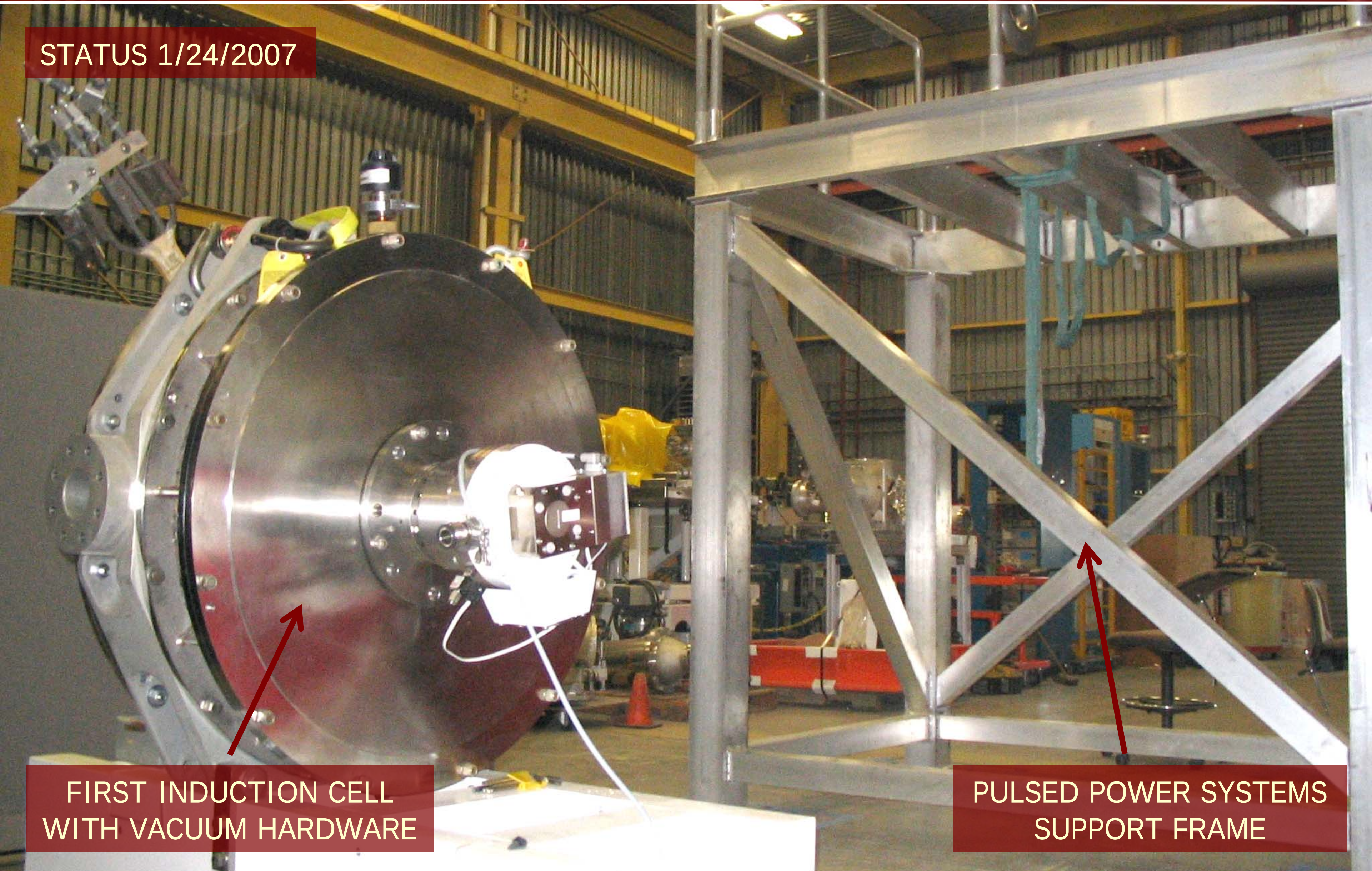
Final Beam Energy:	**2.8 MeV**
Final Spot Size :	**<1 mm diameter**
Final Bunch Length:	**<1 ns** (≅ <1 cm)
Total Charge Delivered:	**0.03 micro-Coulomb** (~ 2×10^{11} particles or I_{max} ~ 42 A)
Normalized Emittance:	**0.4 pi-mm-mrad**

NDCX-2 BUILDING LAYOUT



NDCX-2 is built parallel to the existing NDCX-1 experiment, and can be extended up to 6 MeV final energy within the current building envelope.

NDCX-2 TESTSTAND IS CURRENTLY UNDER CONSTRUCTION TO VERIFY CELL PERFORMANCE AND TO TEST HIGH FIELD SOLENOID



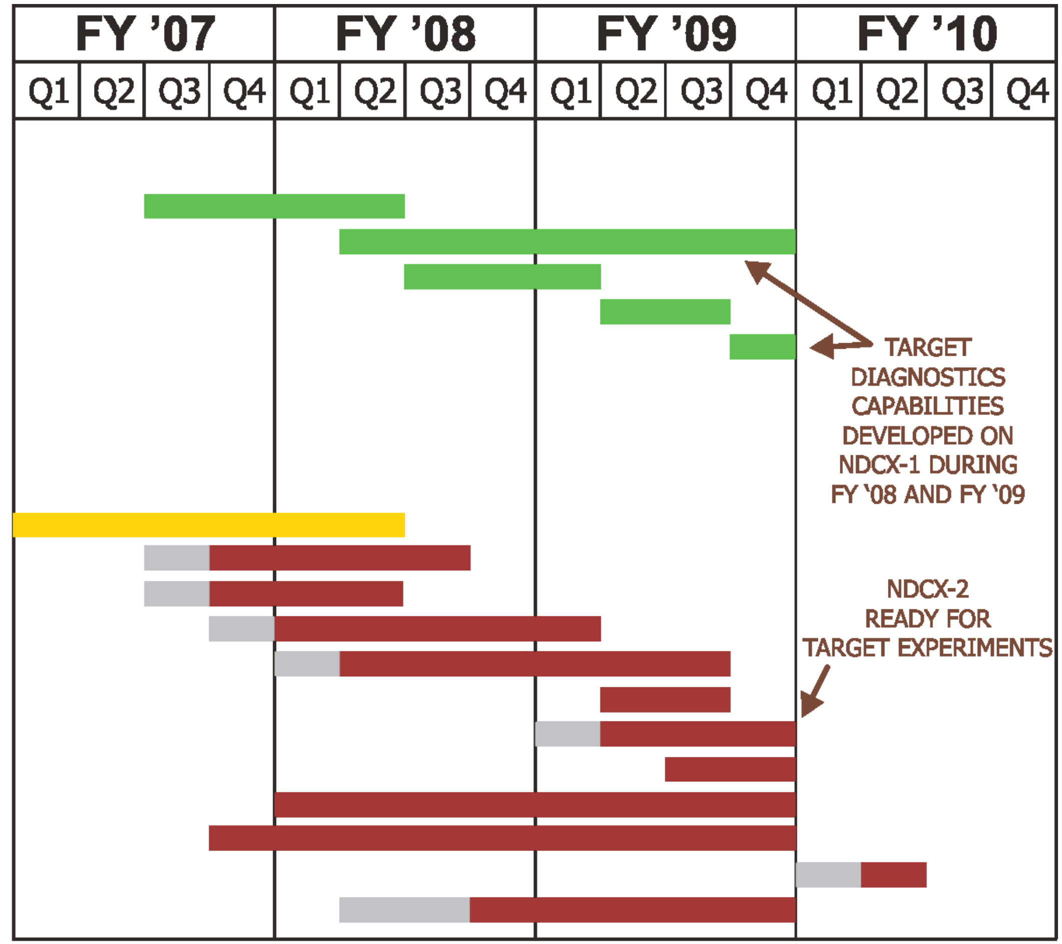
POSSIBLE NDCX-2 SCHEDULE
(PRESIDENT'S BUDGET DOES NOT CURRENTLY SUPPORT NDCX-2 CONSTRUCTION)

NDCX-1

(1) COMPRESSION IMPROVEMENT CAMPAIGN
(2) TARGET EXPERIMENTS
(3) TIME DEPENDENT FOCUSING EXPERIMENTS
(4) PLASMA SOURCE IMPROVEMENT
(5) HYDRO EXPANSION AND TARGET TEMPERATURE MEASUREMENTS

NDCX-2

(1) CONCEPTUAL DESIGN
(2) INJECTOR
(3) INJECTOR SOLENOIDS
(4) PRE-BUNCHING SECTION
(5) ACCELERATOR
(6) DRIFT BUNCHING MODULE (EXISTING)
(7) DRIFT COMPRESSION
(8) TARGET CHAMBER INCL. MAGNET (EXISTING)
(9) CONTROLS
(10) SUPPORT HARDWARE
(11) DOUBLE PULSING HARDWARE
(12) SUPERCONDUCTING FF SOLENOID



NDCX-2 CONSTRUCTION SHOULD BEGIN AS SOON AS POSSIBLE TO CONTINUE WITH THE SUCCESSFUL LINE OF NEUTRALIZED DRIFT COMPRESSION EXPERIMENTS IN THE FUTURE.

NDCX-2 TARGET SHOTS IN FY '09 WOULD REQUIRE APPROX. 400-500 K$/YEAR IN PROCUREMENTS (~10% OF LBNL HIF BUDGET)

NDCX-2

Next Steps for 1 eV Target Heating and Warm Dense Matter Experiments in the U.S. Heavy Ion Fusion Science Virtual National Laboratory

M. Leitner, F. Bieniosek, J. Coleman, E. Henestroza, J-Y. Jung, G. Logan, P. Roy, P. Seidl, W. Waldron
Lawrence Berkeley National Laboratory

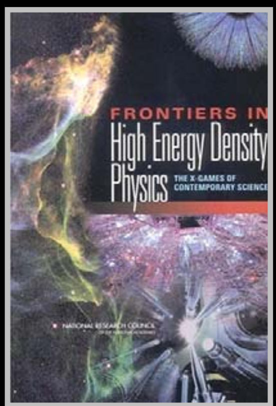
J. Barnard, A. Friedman
Lawrence Livermore National Laboratory

R. Davidson, E. Gilson, I. Kaganovich, A. Sefkow
Princeton Plasma Physics Laboratory

D. Welch
Voss Scientific

HIFS-VNL PROGRAM ADVISORY MEETING
LAWRENCE BERKELEY NATIONAL LABORATORY
FEBRUARY 22ND, 2007

BRAGG HEATING ALLOWS UNIFORM TARGET HEATING FOR WARM DENSE MATTER EXPERIMENTS



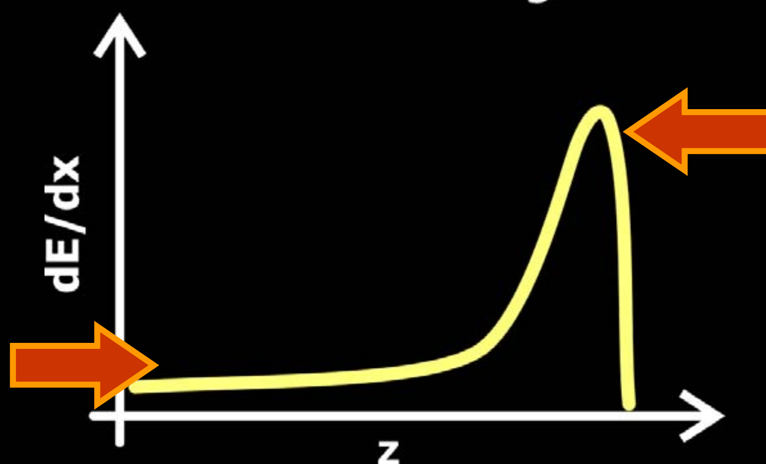
A National Research Council Report and an Interagency Task Force Report have recognized ion beam driven warm dense matter experiments as a major US research thrust in. (Ron Davidson, chair)

HIGH RANGE ION APPROACH

PURSUED BY
e.g. GSI

- requires synchrotron, storage ring
- 40 to 100 GeV heavy ions, 50 - 100 ns
- large targets (several mm)

Ion Energy Loss Rate in Targets



ISOCHORIC HEATING USING SHORT PULSE ($t < t_{hydro}$) HEAVY ION BEAMS

LOW RANGE ION APPROACH (BRAGG HEATING)

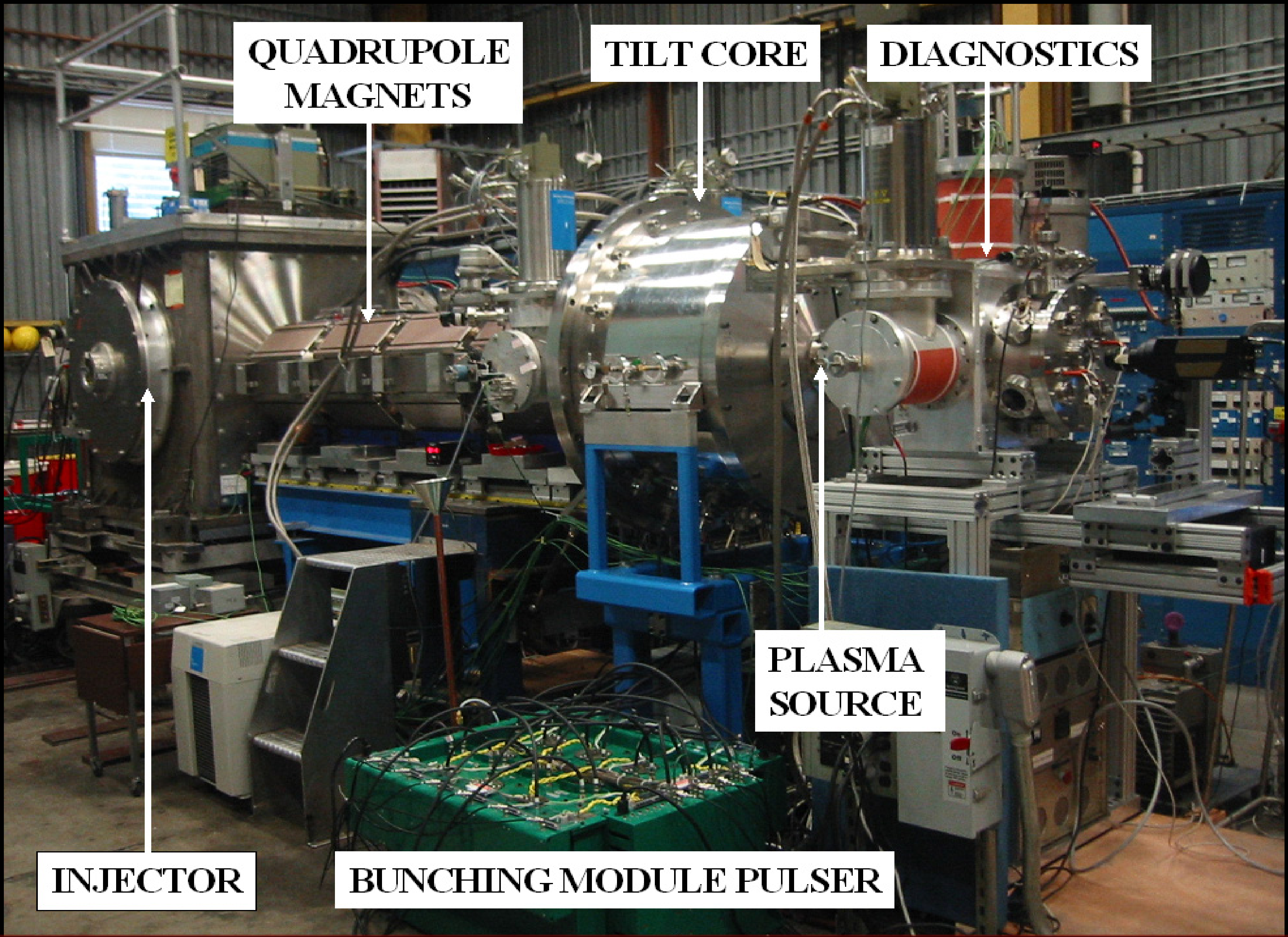
PURSUED BY THE U.S. HIF-VNL

- maximizes heating uniformity and the efficient use of beam energy by placing center of foil at Bragg peak
- low energy (~MeV)
- allows smaller accelerators

HOWEVER:

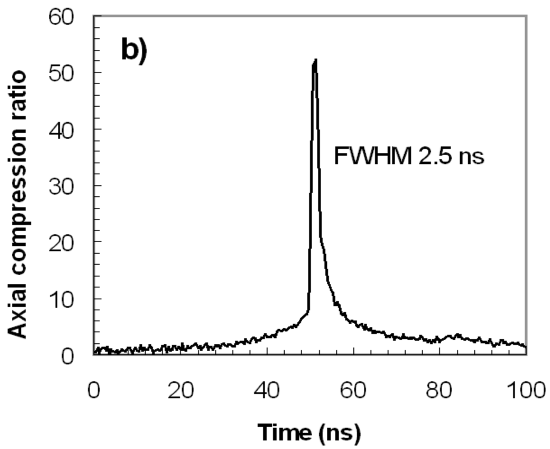
- low energy requires **neutralized drift compression** to focus high space charge beams
- requires **short pulses** to limit hydro motion (1 ns)
- requires **thin targets** (micro-meter), or foams

EXISTING NEUTRALIZED DRIFT COMPRESSION EXPERIMENT (NDCX-1) CAN PROVIDE SHORT ION PULSES FOR FIRST WDM EXPERIMENTS



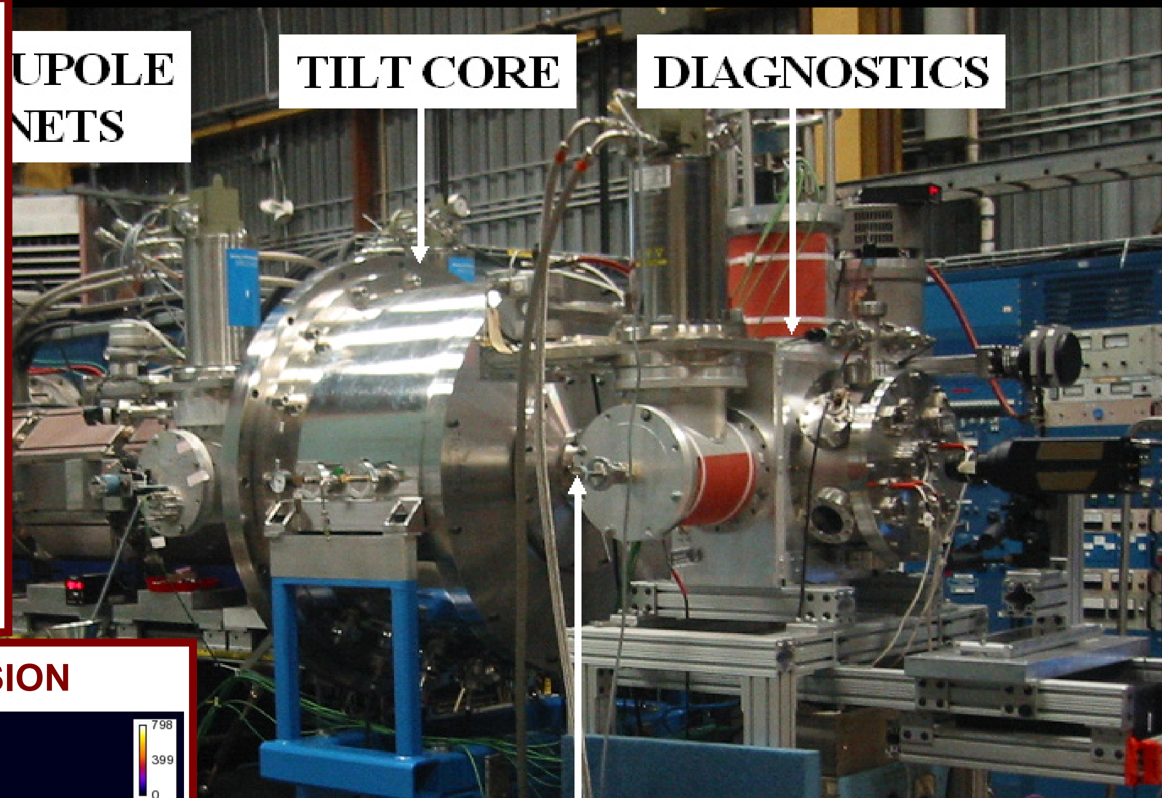
EXISTING NEUTRALIZED DRIFT COMPRESSION EXPERIMENT (NDCX-1) CAN PROVIDE SHORT ION PULSES FOR FIRST WDM EXPERIMENTS

LONGITUDINAL COMPRESSION

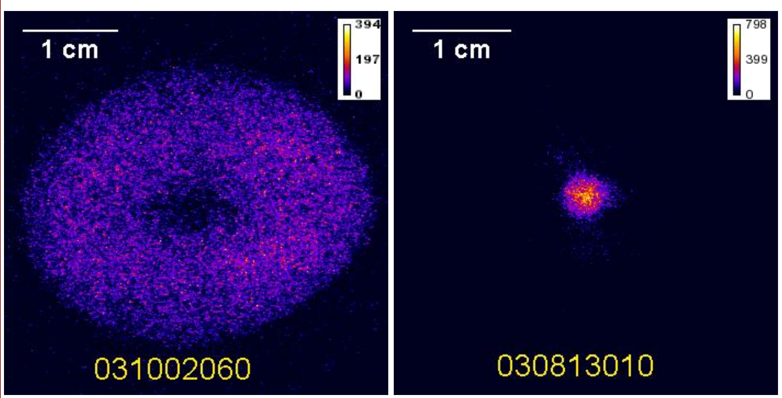


up to 60 times compression

FWHM: 2.5 ns

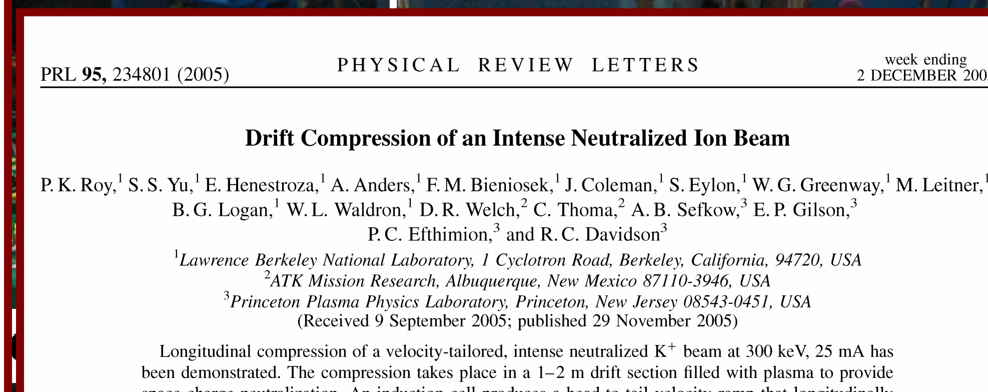


TRANSVERSE COMPRESSION



un-neutralized
FWHM: 2.71 cm

neutralized
FWHM: 2.14 mm



PRL **95,** 234801 (2005) PHYSICAL REVIEW LETTERS week ending 2 DECEMBER 2005

Drift Compression of an Intense Neutralized Ion Beam

P. K. Roy,[1] S. S. Yu,[1] E. Henestroza,[1] A. Anders,[1] F. M. Bieniosek,[1] J. Coleman,[1] S. Eylon,[1] W. G. Greenway,[1] M. Leitner,[1] B. G. Logan,[1] W. L. Waldron,[1] D. R. Welch,[2] C. Thoma,[2] A. B. Sefkow,[3] E. P. Gilson,[3] P. C. Efthimion,[3] and R. C. Davidson[3]

[1]*Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, California, 94720, USA*
[2]*ATK Mission Research, Albuquerque, New Mexico 87110-3946, USA*
[3]*Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543-0451, USA*
(Received 9 September 2005; published 29 November 2005)

Longitudinal compression of a velocity-tailored, intense neutralized K^+ beam at 300 keV, 25 mA has been demonstrated. The compression takes place in a 1–2 m drift section filled with plasma to provide space-charge neutralization. An induction cell produces a head-to-tail velocity ramp that longitudinally

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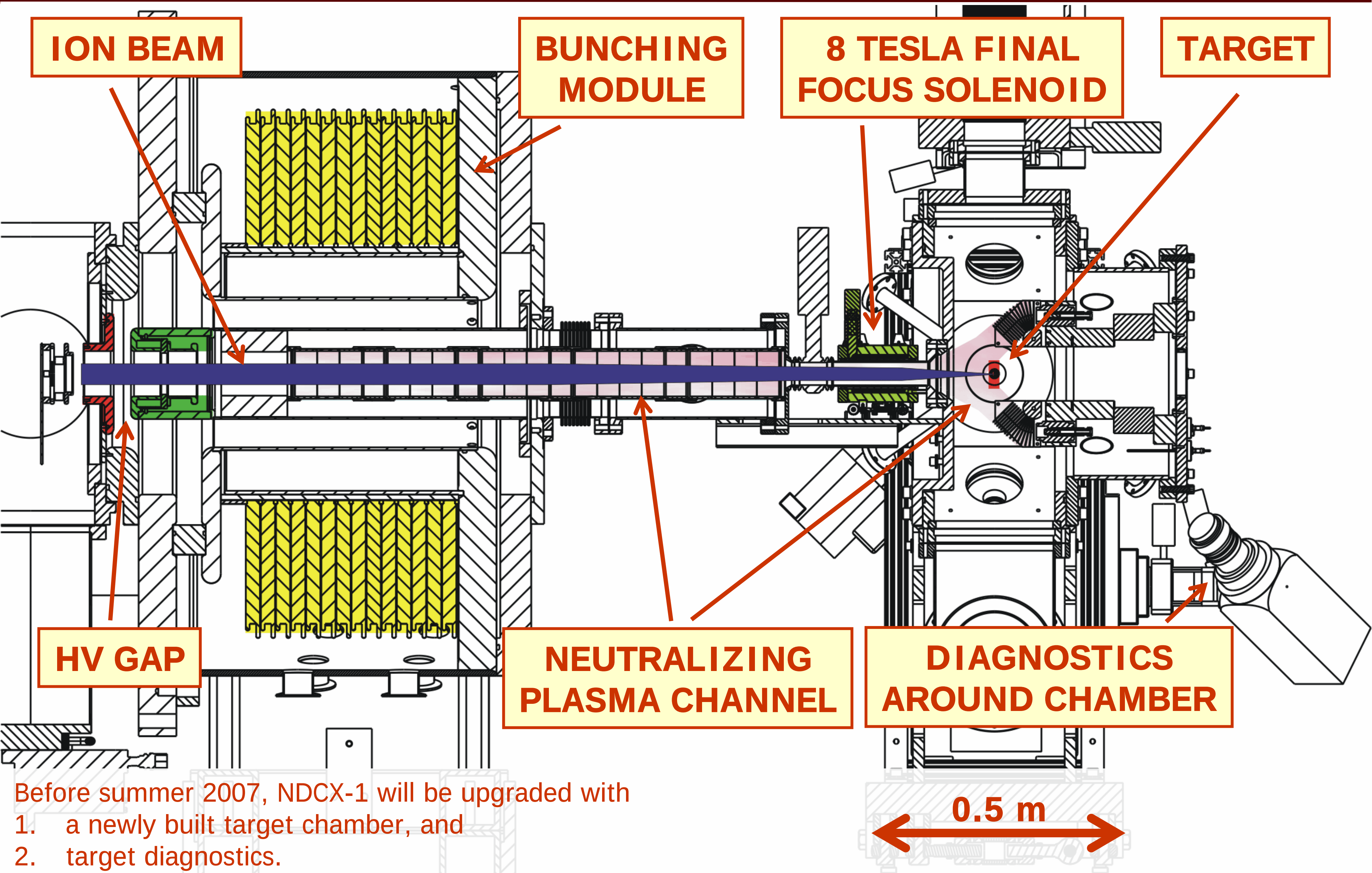

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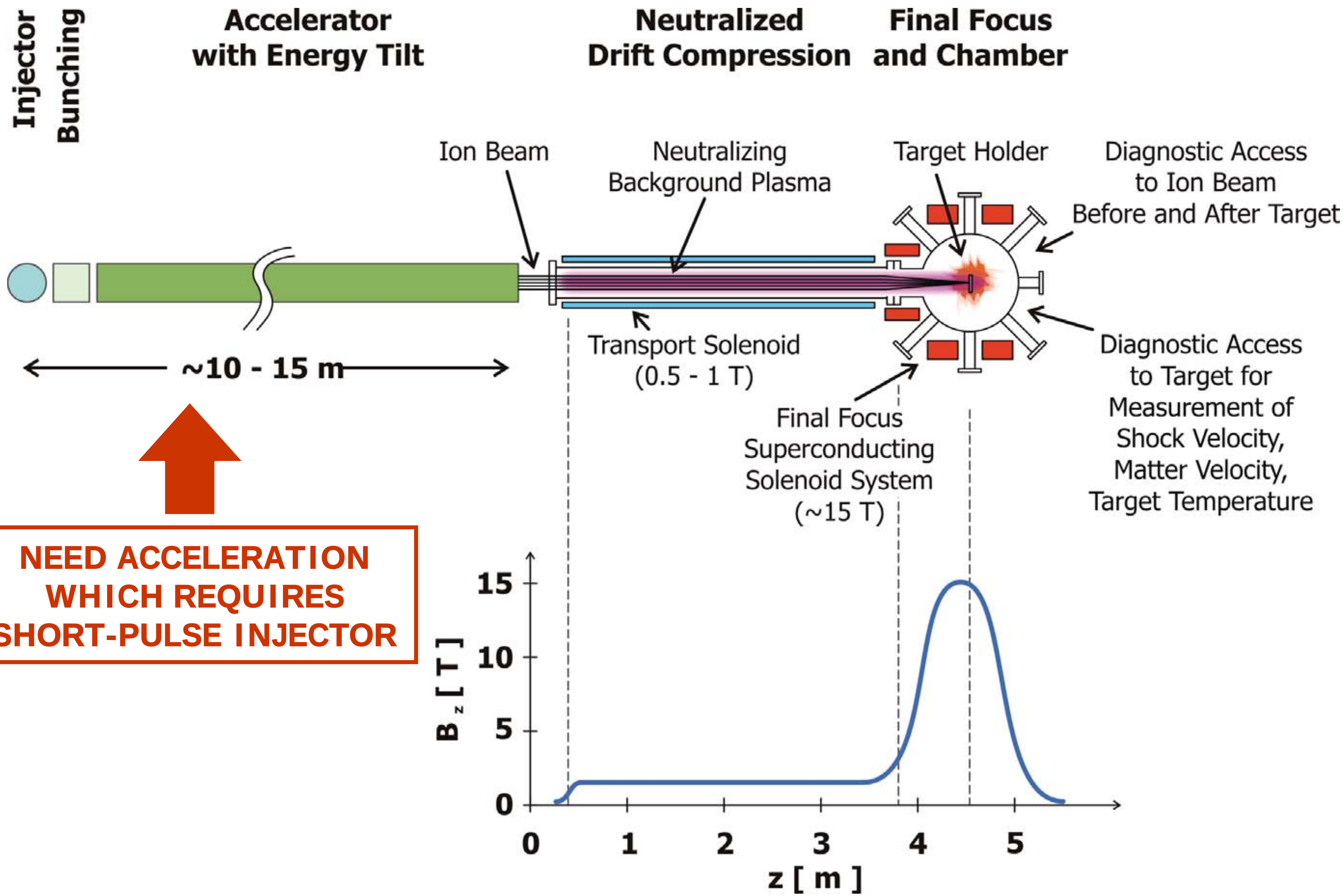
BUT acceleration is still missing for >1 eV uniform heating!

NDCX-2 WILL REQUIRE AN ACCELERATION SECTION AND THEREFORE A SHORT-PULSE INJECTOR



NEED ACCELERATION WHICH REQUIRES SHORT-PULSE INJECTOR

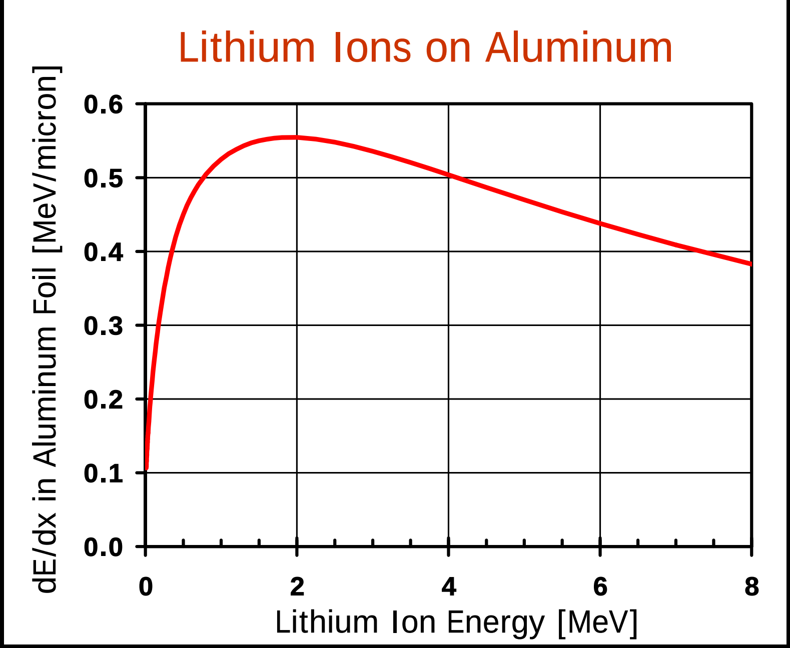
NDCX-2 IS THE NEXT STEP TOWARDS AN ION DRIVEN HEDP USER FACILITY

GOALS FOR NDCX-2:

- Integrated compression, acceleration, and focusing sufficient to reach 1 eV in targets
- Incorporate short-pulse injector to minimize accelerator cost
- Diagnostics, target, and target chamber development for the HEDP user facility to be constructed after NDCX-2

TARGET POINT DESIGN:

Bragg Peak:	1.8 MeV
dE/dx at Bragg Peak:	2 MeV cm^2 / mg
Ion Range:	~5 micron
Required Fluence for > 1 eV Heating:	>29 J/cm^2



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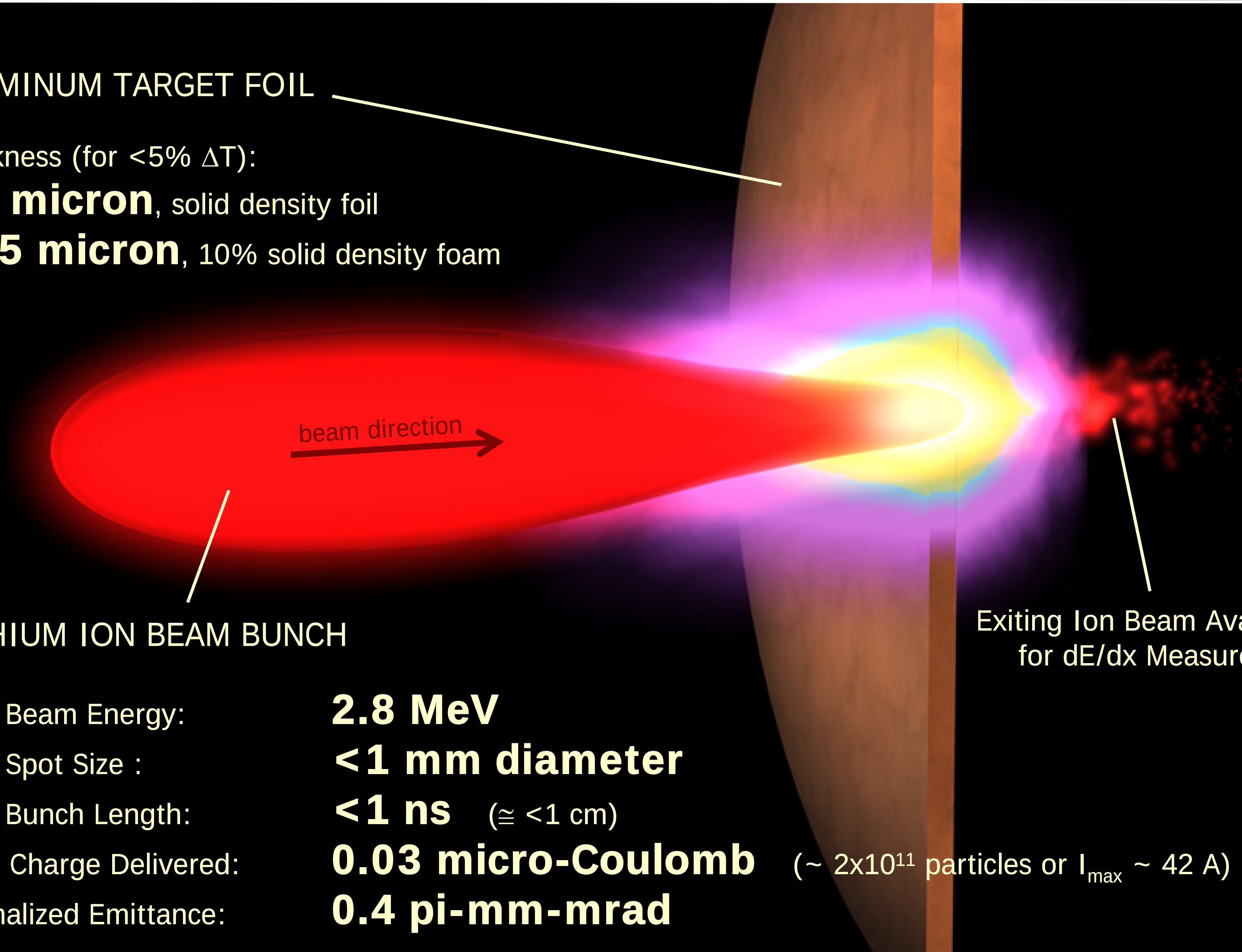

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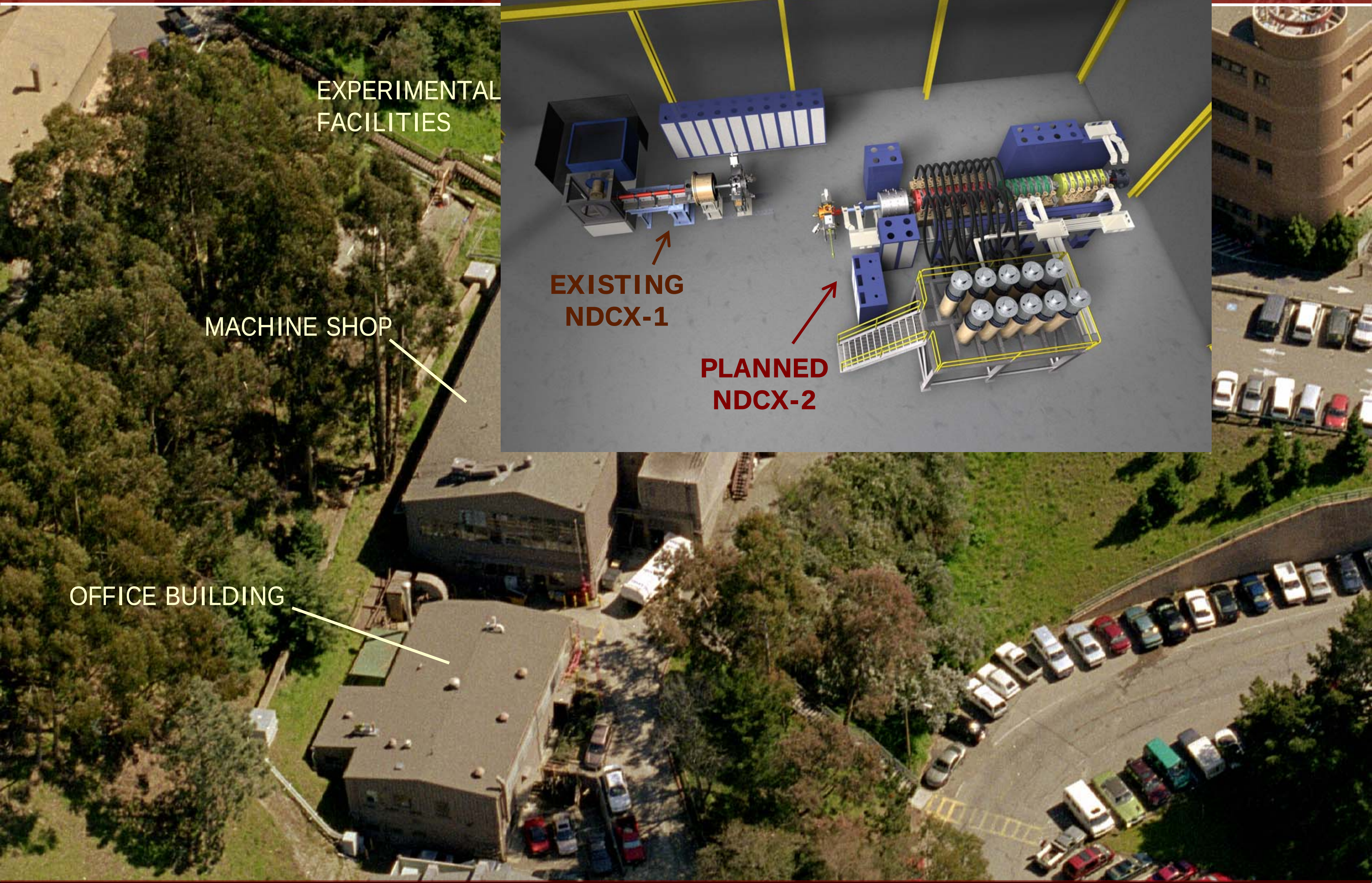

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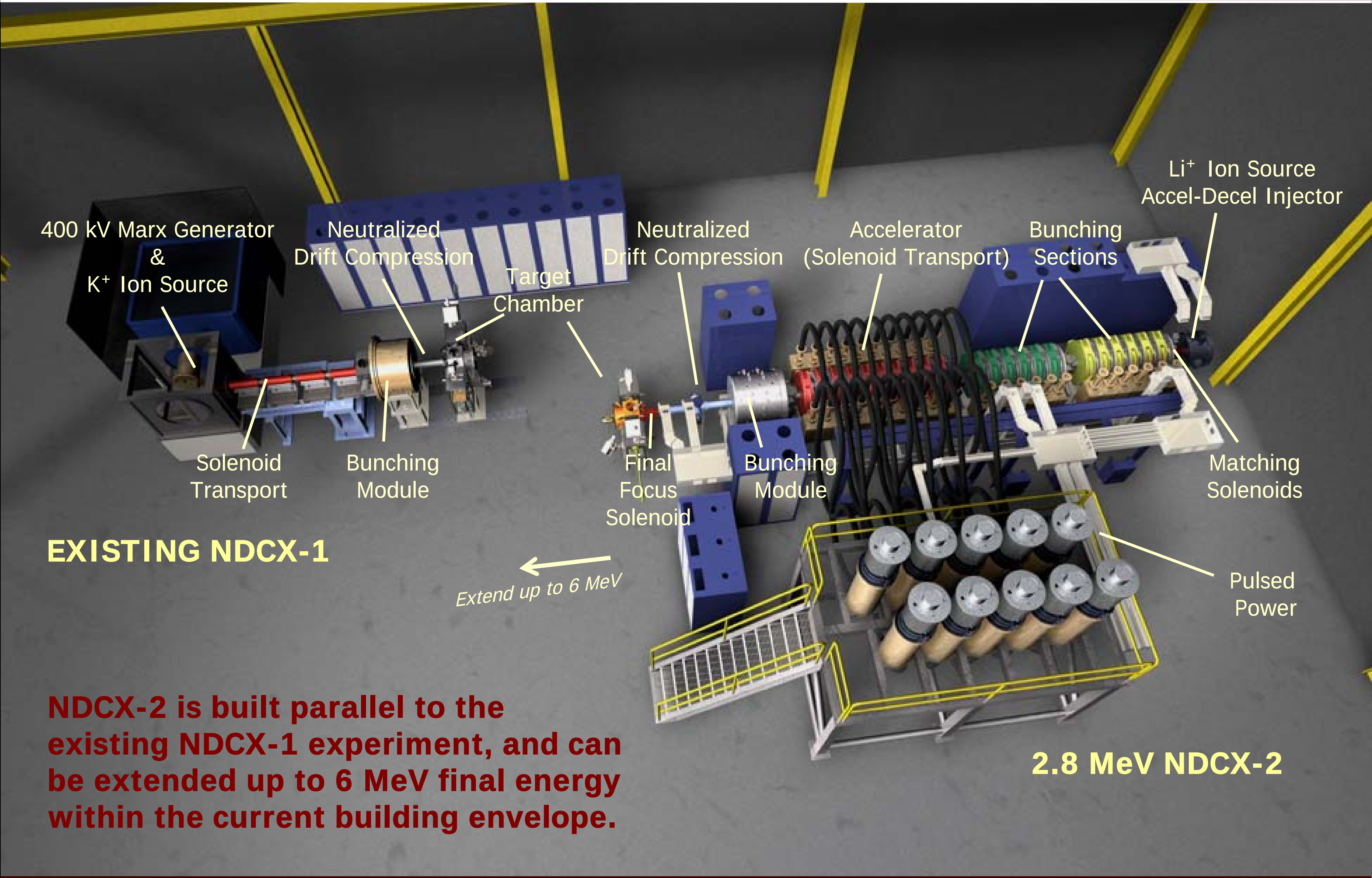

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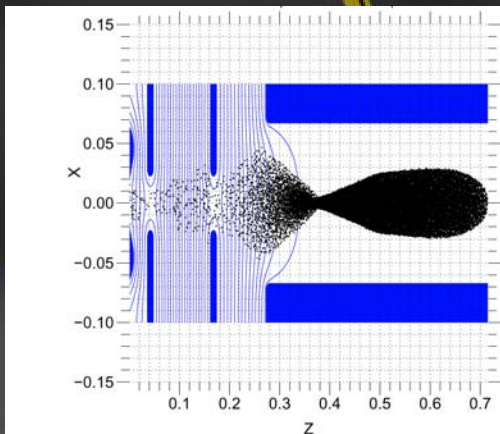
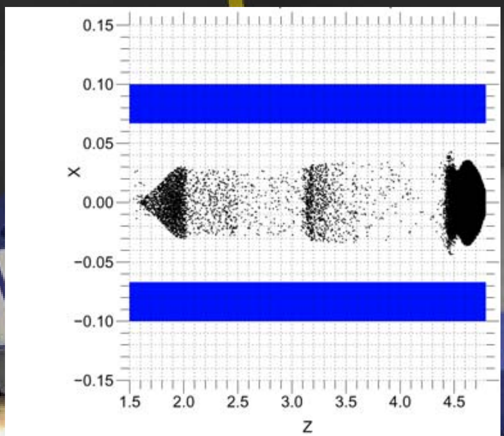
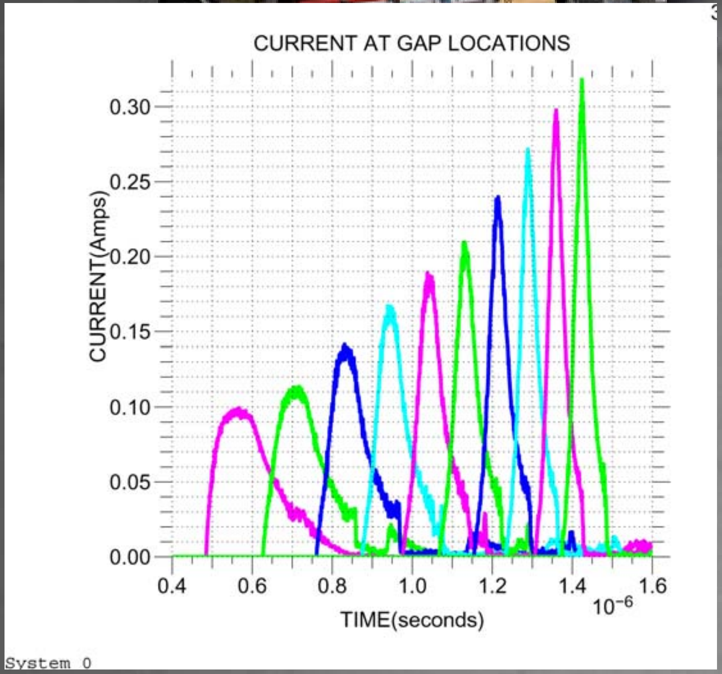
CONSTRUCTION STEP 1:
NDCX-2 INJECTOR AND BUNCHING SECTION

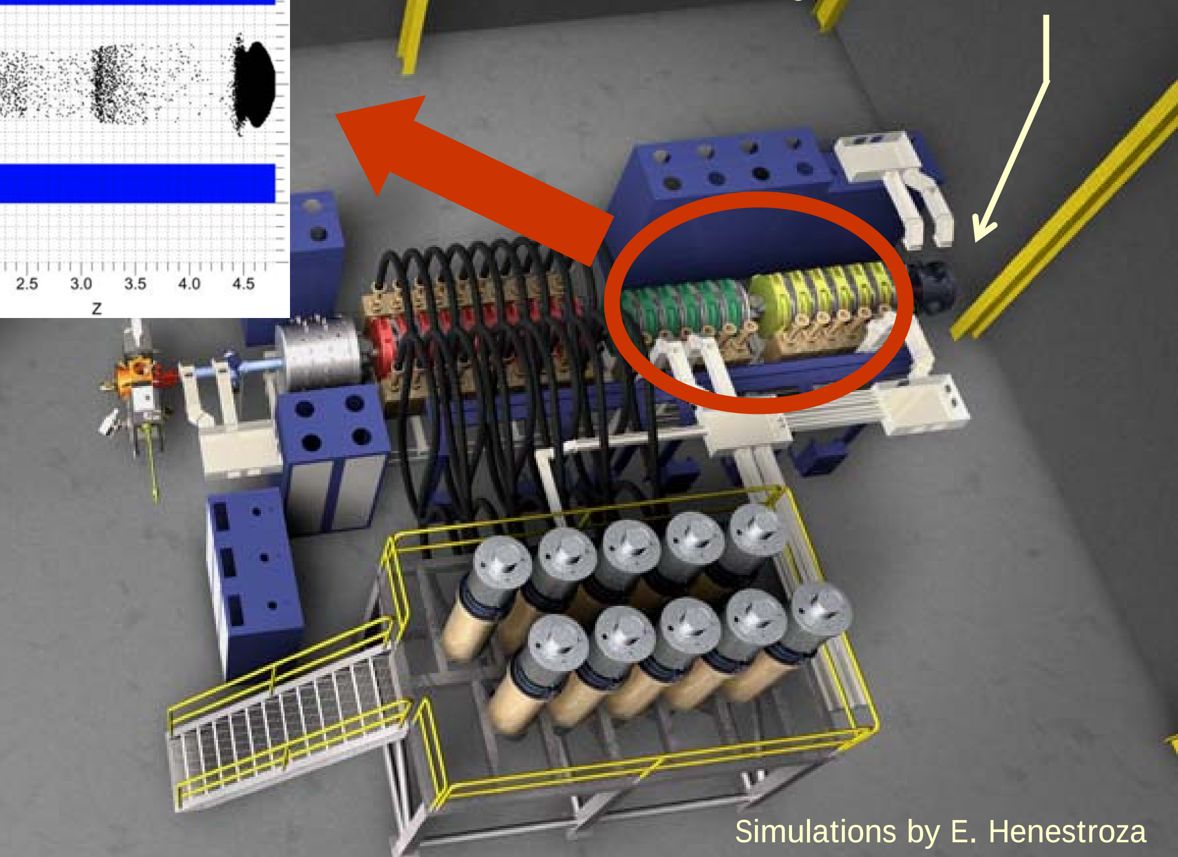
AT INJECTOR:



AFTER BUNCHING:







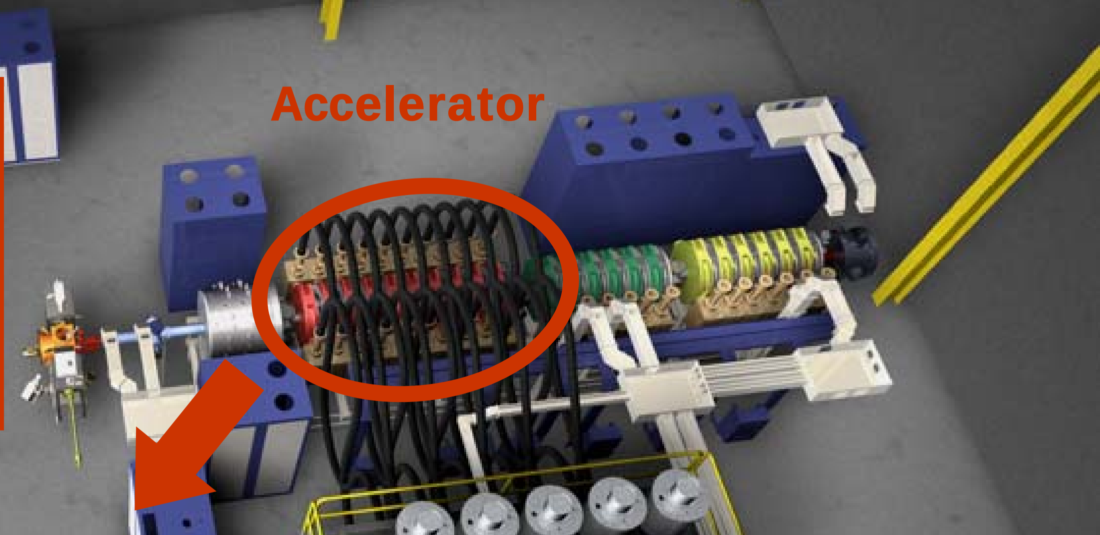
1.4 inch Ø Li+ Source
100 mA (10 mA/cm^2)
Source Pulse: ~500ns with 160 ns Rise Time
Total Charge: 0.03 micro-Coulomb

Simulations by E. Henestroza

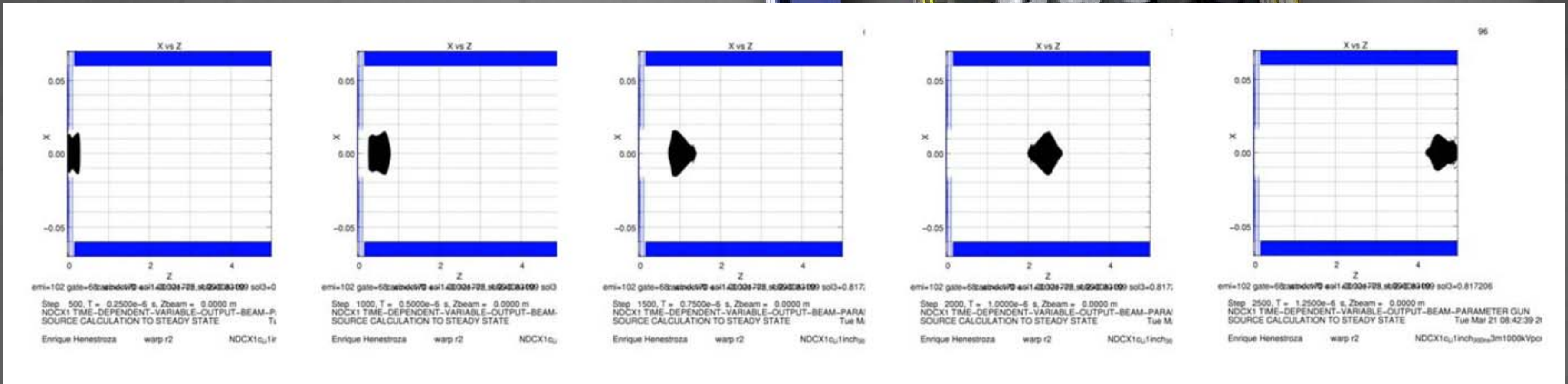
Bunching Section Compresses Beam for Further Transport in Short Pulse (70 ns) Induction Cells

CONSTRUCTION STEP 2: NDCX-2 ACCELERATOR

<u>EXISTING INDUCTION CELLS</u> FROM THE LLNL ATA FACILITY CAN BE USED FOR THE NDCX-2 BUNCHING AND ACCELERATION SECTIONS.

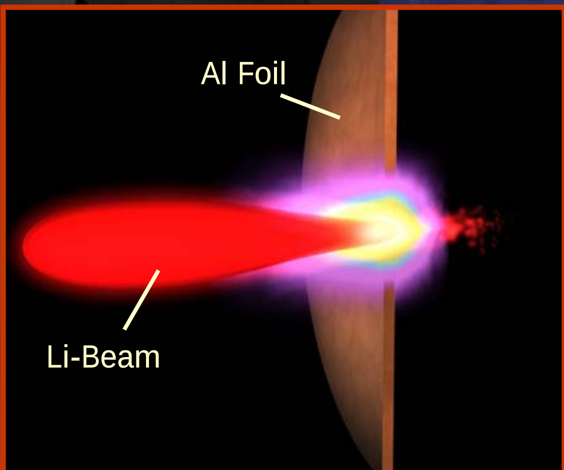


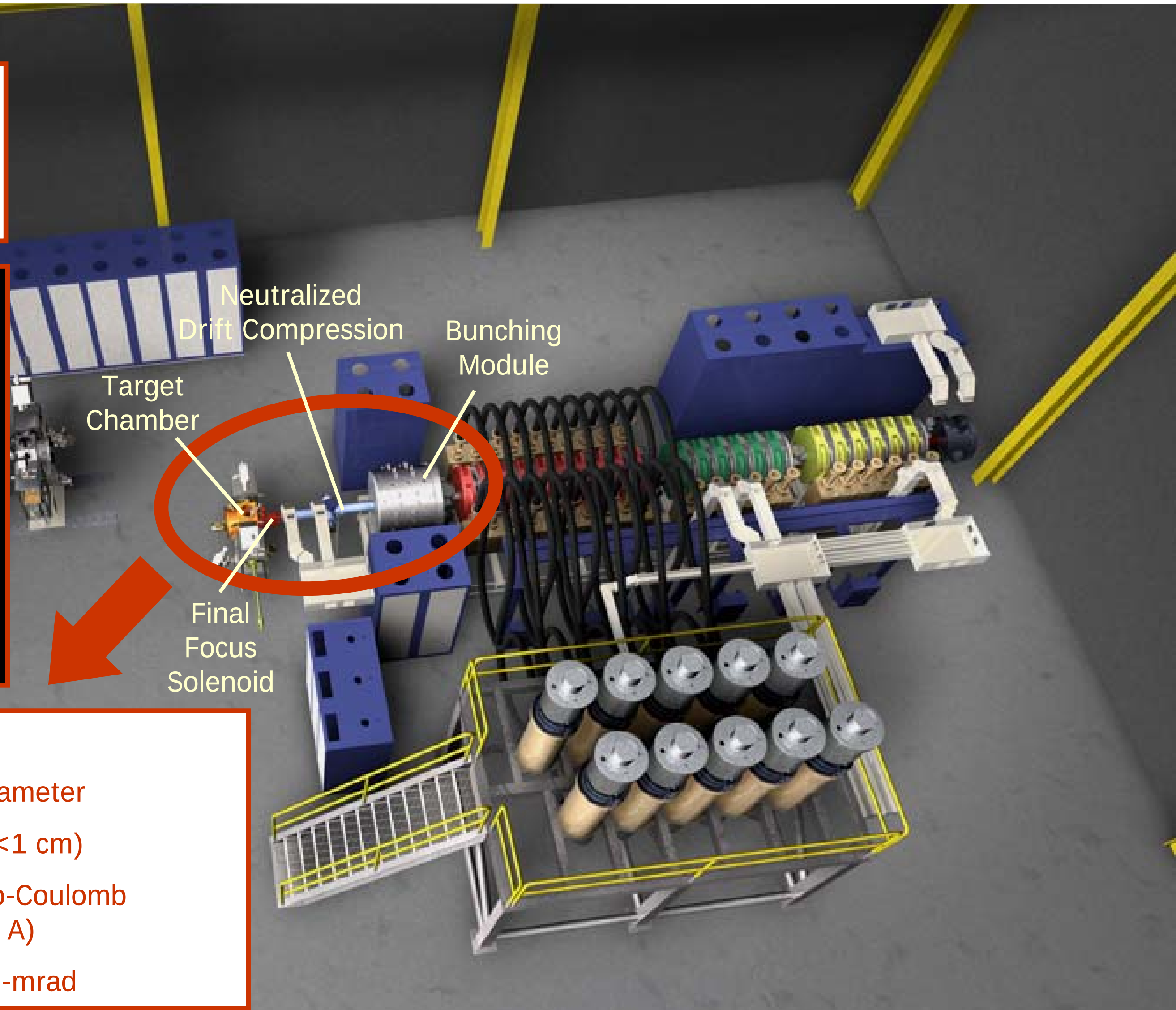
SIMULATIONS ARE IN PROGRESS:



CONSTRUCTION STEP 3: NDCX-2 NEUTRALIZED DRIFT COMPRESSION AND FINAL FOCUS

NDCX-2 TARGET POINT DESIGN For >1 eV HEATING





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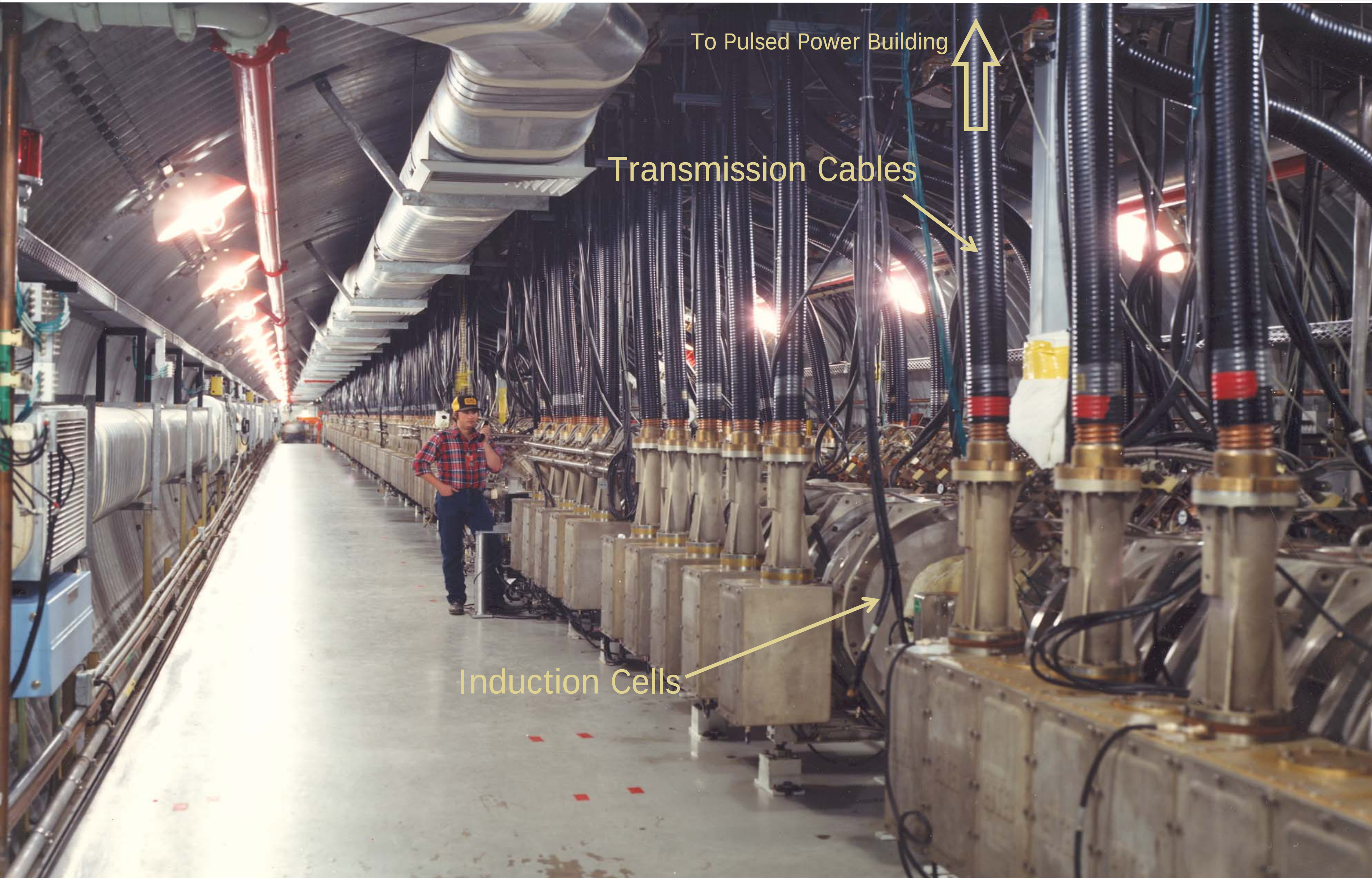
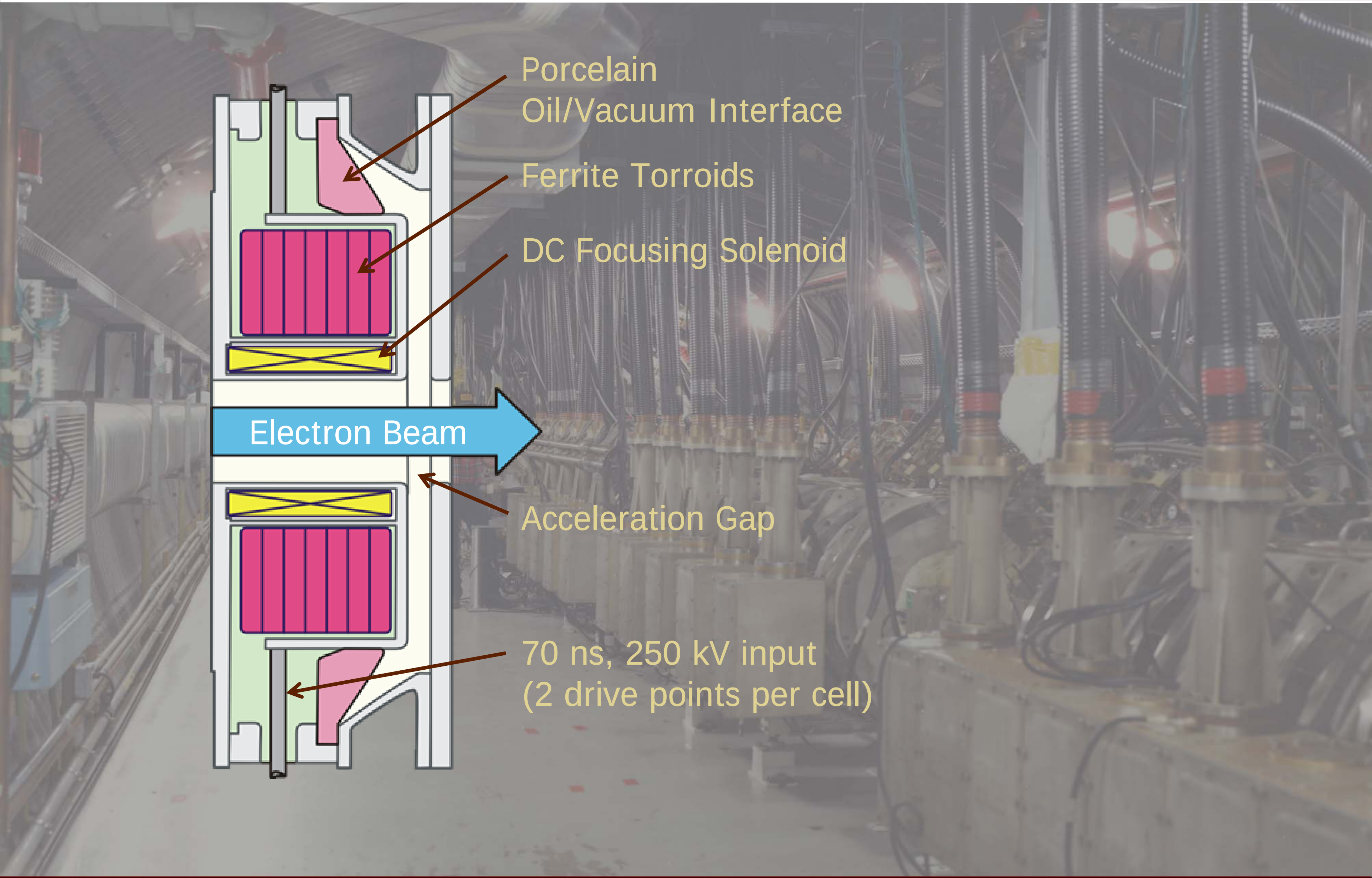
REQUIRED HARDWARE SIMILAR TO NDCX-1

SHORT PULSE INDUCTION CELLS (250 kV, 70 ns) ARE AVAILABLE FROM SHUT DOWN LLNL ATA FACILITY



ATA INDUCTION CELLS HAVE TO BE REFURBISHED WITH STRONGER SOLENOID FOCUSING MAGNETS



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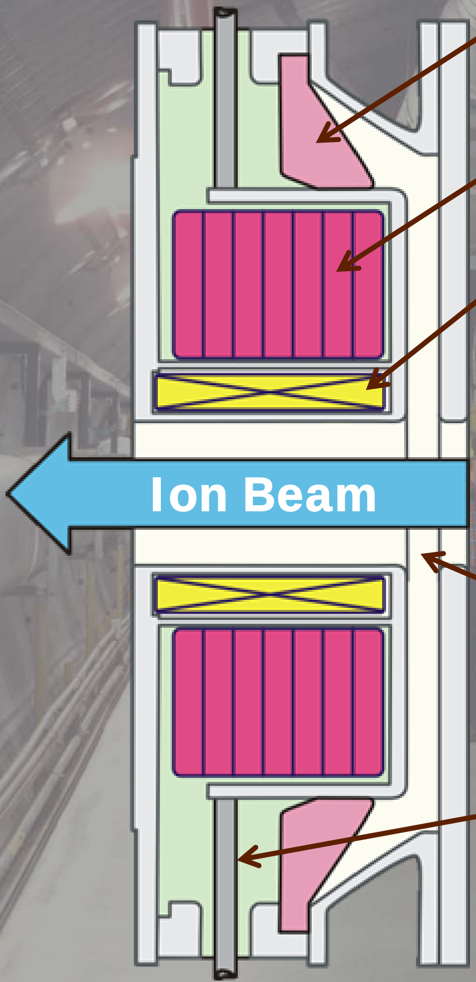


Porcelain
Oil/Vacuum Interface

Ferrite Torroids

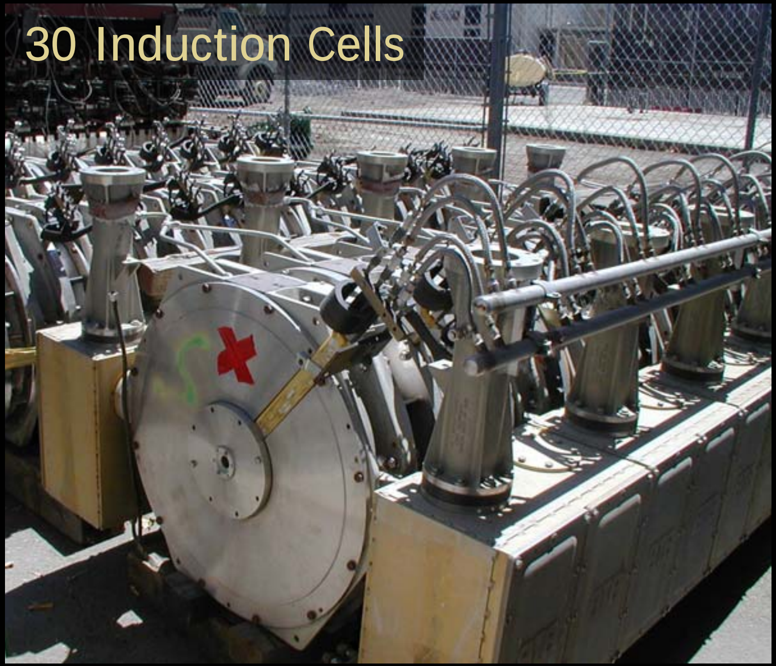
Focusing Solenoid
Pulsed, 1.5-3 Tesla

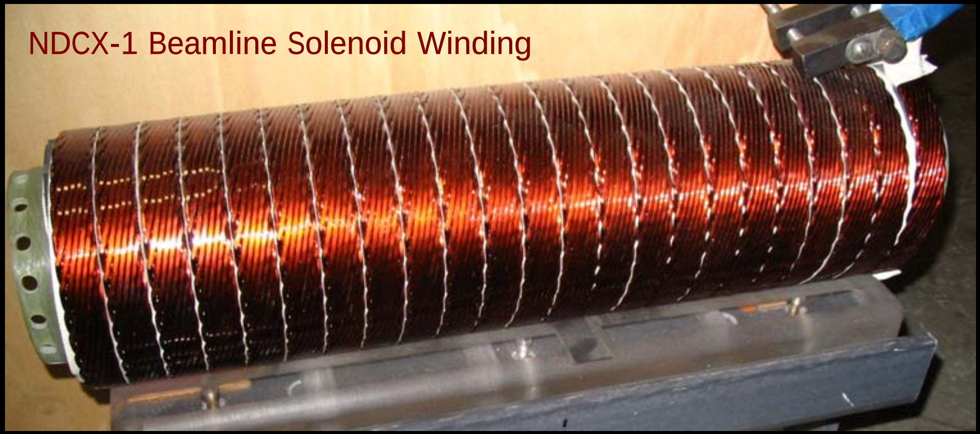
Acceleration Gap

70 ns, 250 kV input
(2 drive points per cell)

solenoid transport scales favorably for low-energy, high-current ion beam transport

NDCX-2 TESTSTAND IS CURRENTLY UNDER CONSTRUCTION TO VERIFY CELL PERFORMANCE AND TO TEST HIGH FIELD SOLENOID





- We have shipped hardware for 30 induction cells to LBNL.
- We are building a high-field pulsed solenoid to fit into the induction cell.
- Hardware for two cell units has been refurbished to be installed at a teststand at LBNL.

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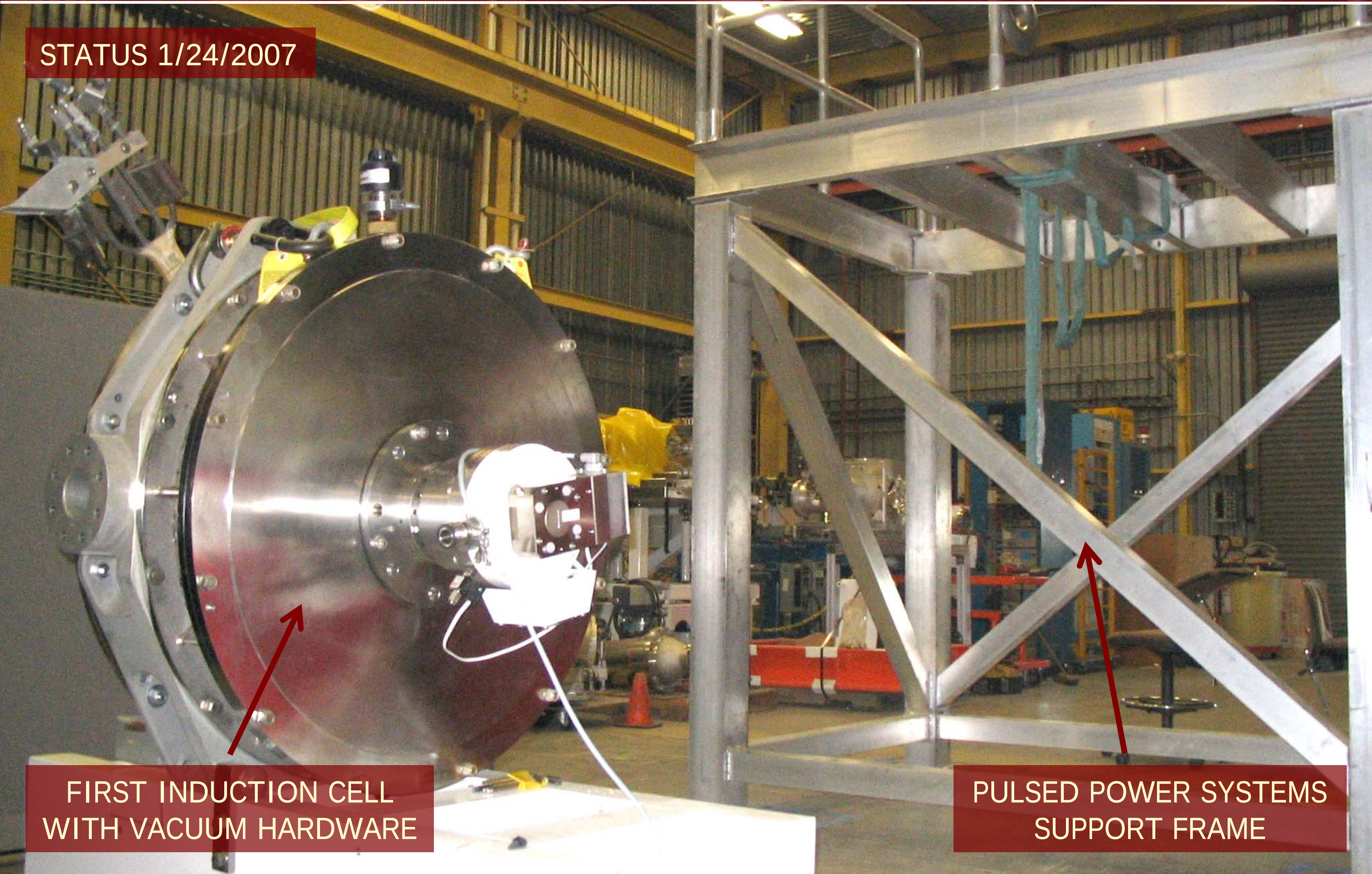
STATUS 1/24/2007



FIRST INDUCTION CELL WITH VACUUM HARDWARE

PULSED POWER SYSTEMS SUPPORT FRAME

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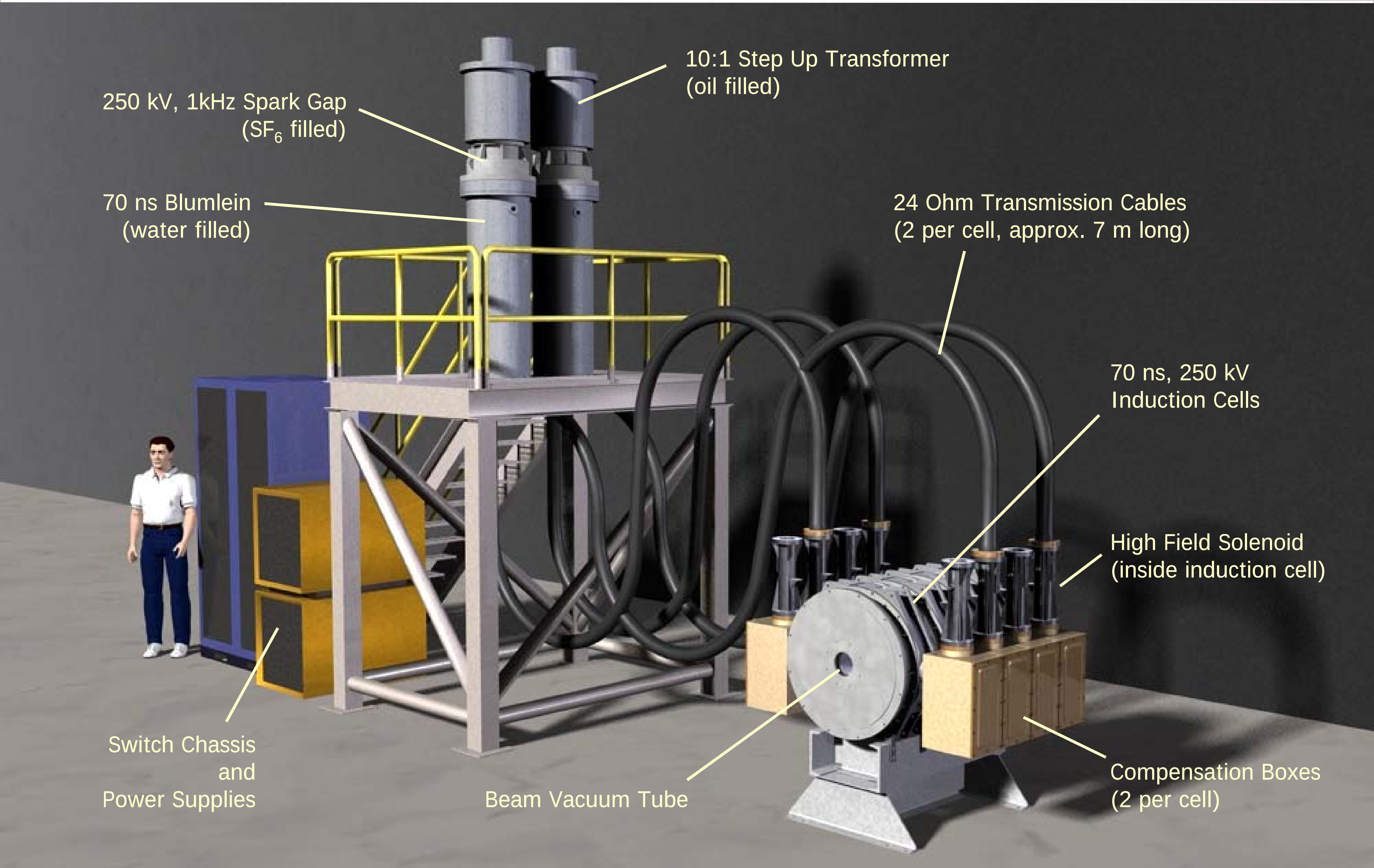


SUMMARY

- NDCX-2 will be able to provide 1 ns pulses at less than 1 mm spot radius for >1 eV target heating.
- The first phase of NDCX-2 will consist of a 2.8 MeV induction linac. Lithium ions hitting an aluminum foil or foam will be used for first WDM experiments.
- NDCX-2 will be a versatile and expandable WDM driver platform with plenty of future upgrade options. For instance, the NDCX-2 architecture allows the development of double-pulsing techniques for tailored target heating experiments or the development of time-dependent solenoid focusing correction for increased target heating.
- In later phases, the addition of more ATA induction cells will increase the NDCX-2 final beam energy. Therefore, different ion and target material choices – including cryogenically cooled target layers - can be explored.
- In addition to its WDM mission, NDCX-2 constitutes an integrated accelerator experiment with compression, acceleration, and focusing of an intense ion beam. NDCX-2 will utilize a short-pulse injector and accelerator, high-field solenoid transport, neutralized drift compression, agile wave-form correction, and high-field final focus magnets. Therefore, NDCX-2 could have a strong synergistic effect on the development of future heavy ion fusion driver concepts for energy production as well.

NDCX-2

FURTHER BACKGROUND INFORMATION

DOE MISSION NEED DOCUMENT FOR A HEDP USER FACILITY REQUIRES A PRECEDING R&D FACILITY (NDCX-2)

Justification of Mission Need CD-0 for the Integrated Beam High Energy Density Physics Experiment (IB-HEDPX)

The overall IB-HEDPX program addresses a critical issue for high energy density physics in the near term, and inertial fusion energy in the long term, namely, the integration of the generation, injection, acceleration, transport, compression, and focusing of an ion beam of sufficient intensity for creating high energy density matter and fusion ignition conditions. The heavy ion beams required are very intense yet virtually collisionless, so that the beam distribution retains a long memory of effects from each region the beam passes through. Thus, the beam distribution that heats the target depends on the evolution of the beam distribution in all of the upstream regions. An integrated beam experiment IB-HEDPX is therefore essential for testing integrated beam models, and for accurate prediction of the beam energy deposition in target physics experiments. A secondary, but equally important, objective of the program is to create a critically needed user facility for experimental research in warm dense matter. Such a facility is lacking at present.

NDCX-II, requiring approximately $5 M hardware as an upgrade of the present NDCX-1 facility in Year 1 and 2, is necessary R&D to assess the performance requirements of injection, acceleration and focusing of short pulses needed for the IB-HEDPX .

APPROVAL

This Justification of Mission Need for the IB-HEDPX Project is satisfactory and Critical Decision 0 (CD-0) is approved and the Project is authorized to proceed with Conceptual Design activities.

Submitted by:

Francis Thio — 12/1/2005

Y. C. Francis Thio
Program Manager
Research Division
Office of Fusion Energy Sciences

Date

Approved by:

12/1/05

N. Anne Davies
Associate Director for Fusion Energy Sciences
Office of Science

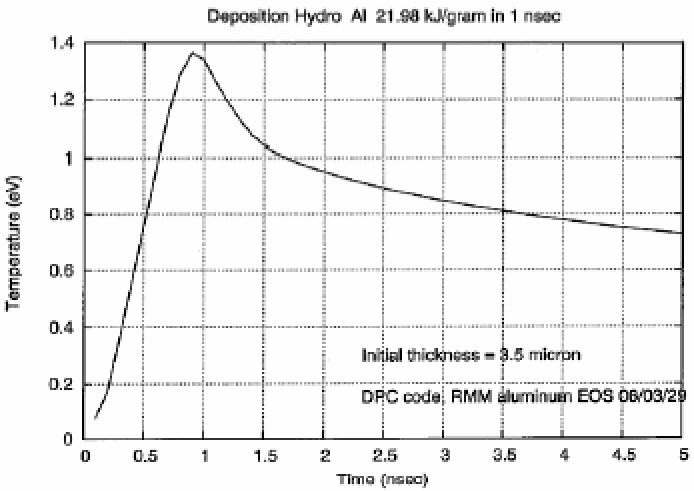
Date

NDCX-2 WILL REACH >1 eV TARGET HEATING

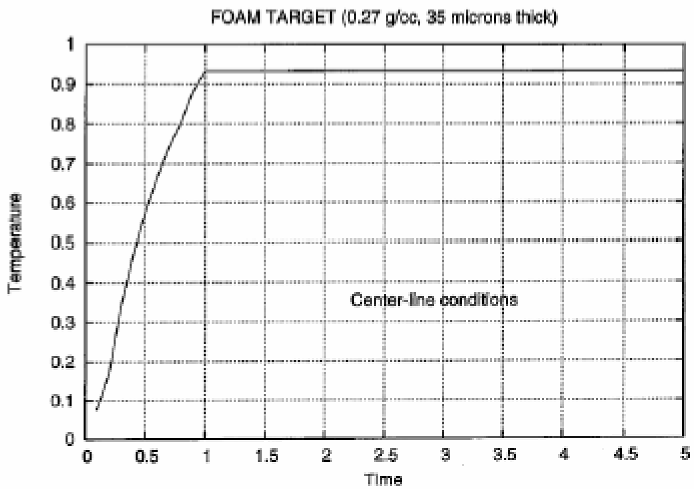
2.8 MeV Lithium Ions on Aluminum

Simulations by R. More using latest EOS of uniformly heated foil

3.5 μ, solid density



35 μ, 10% density foam



> 1 eV TARGET HEATING

NDCX-2 INJECTOR

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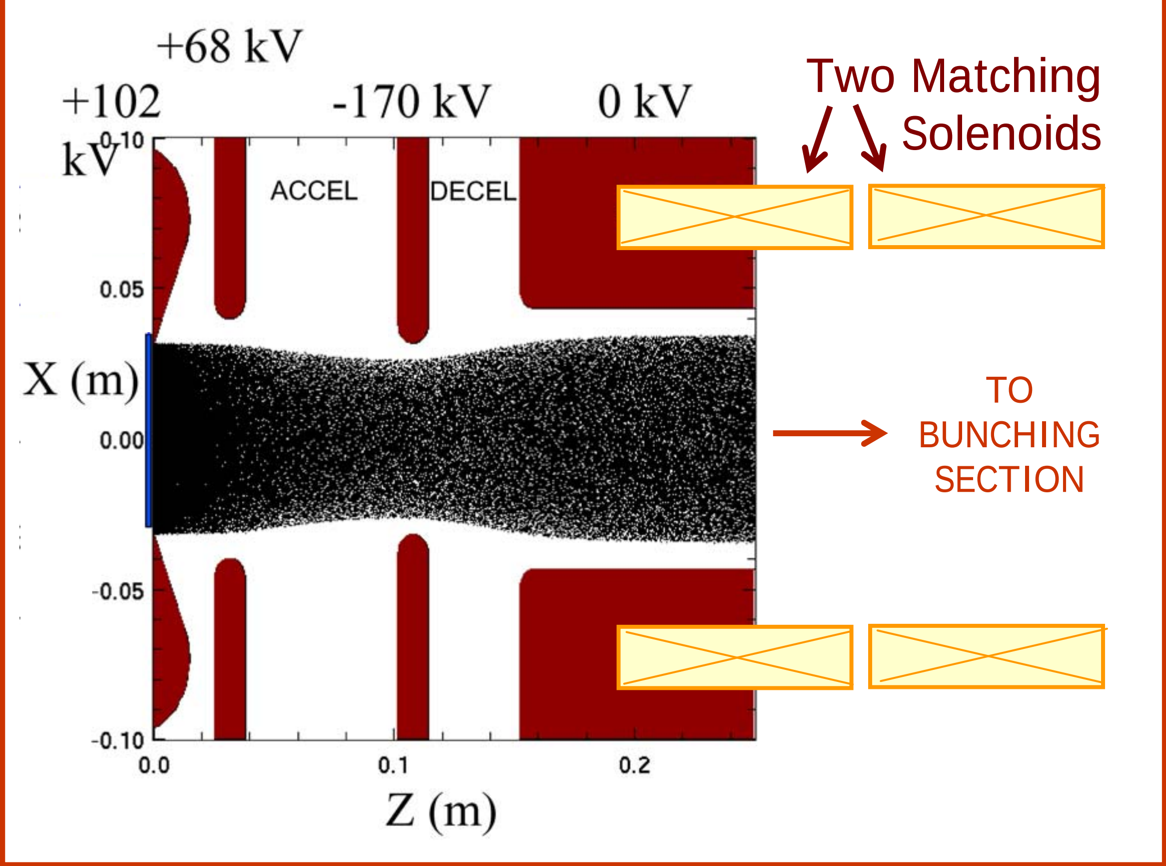
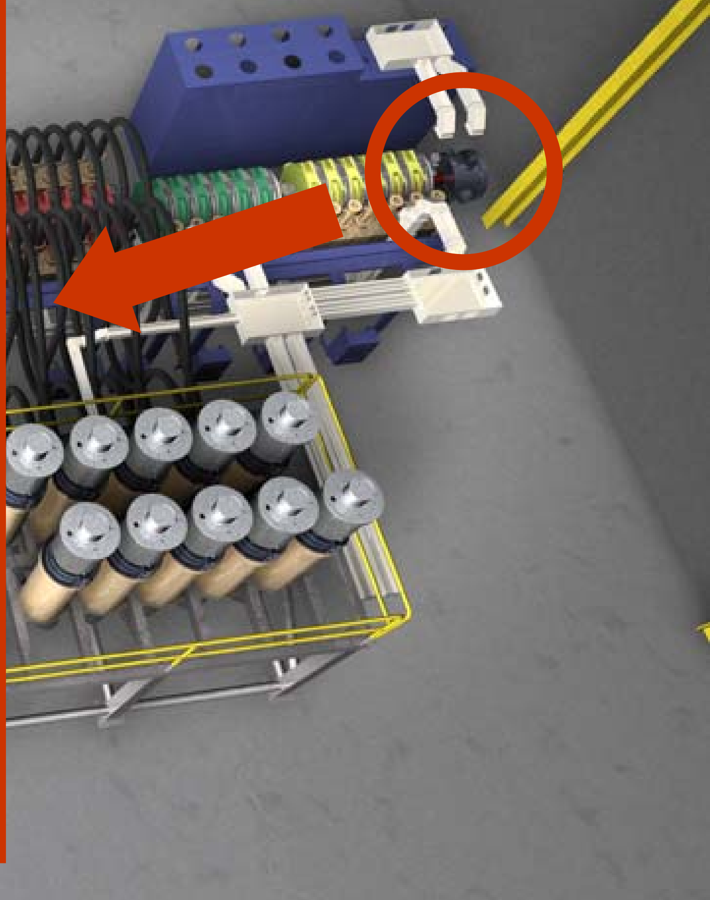
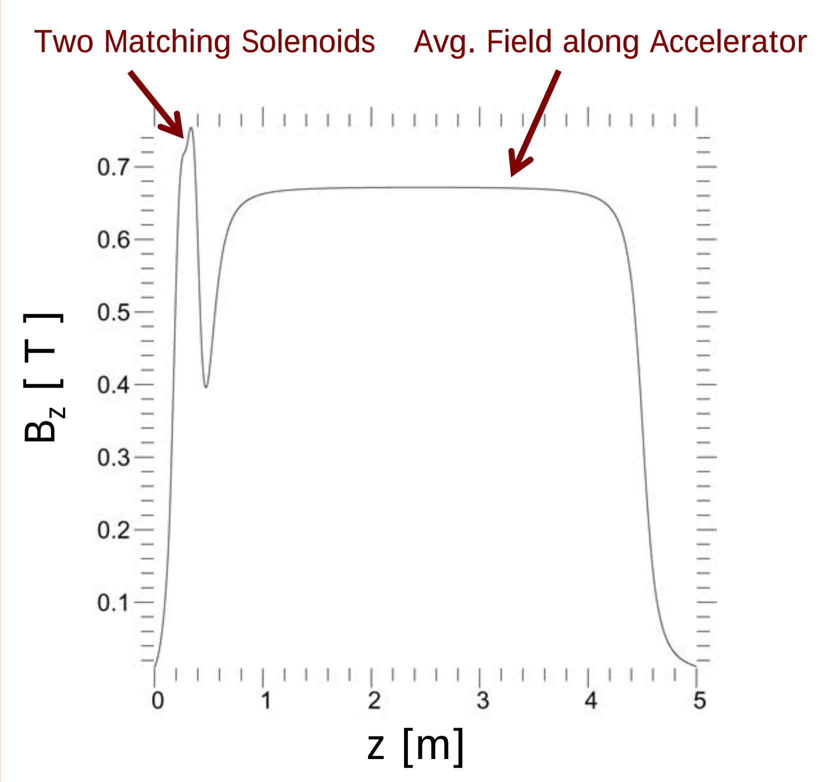
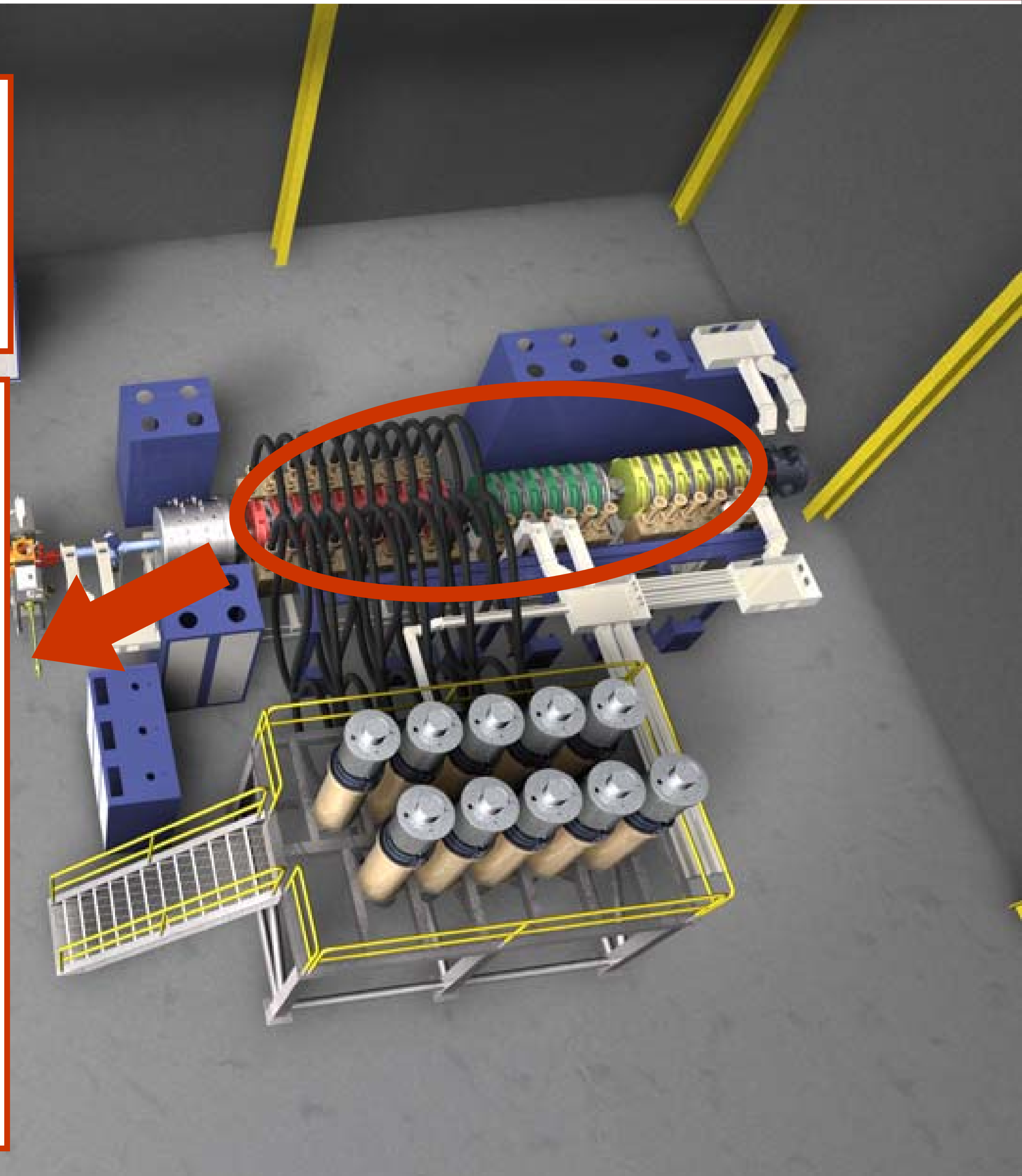




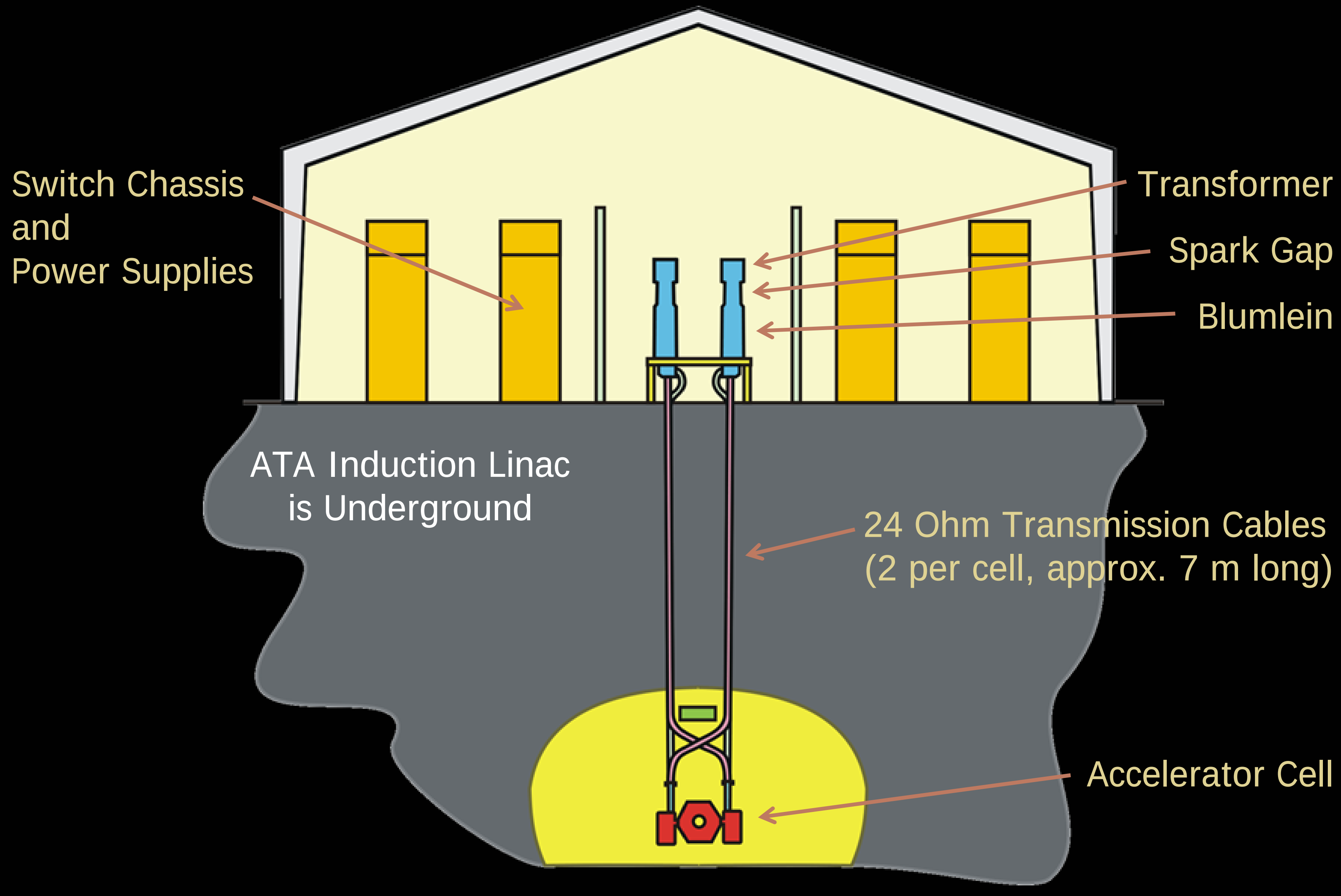
NDCX-2 SOLENOID TRANSPORT AND ACCELERATOR

SOLENOID TRANSPORT
UP TO 1.5 TESLA
PULSED SOLENOIDS
Solenoid transport scales favorably
for low-energy, high-current ion beams.

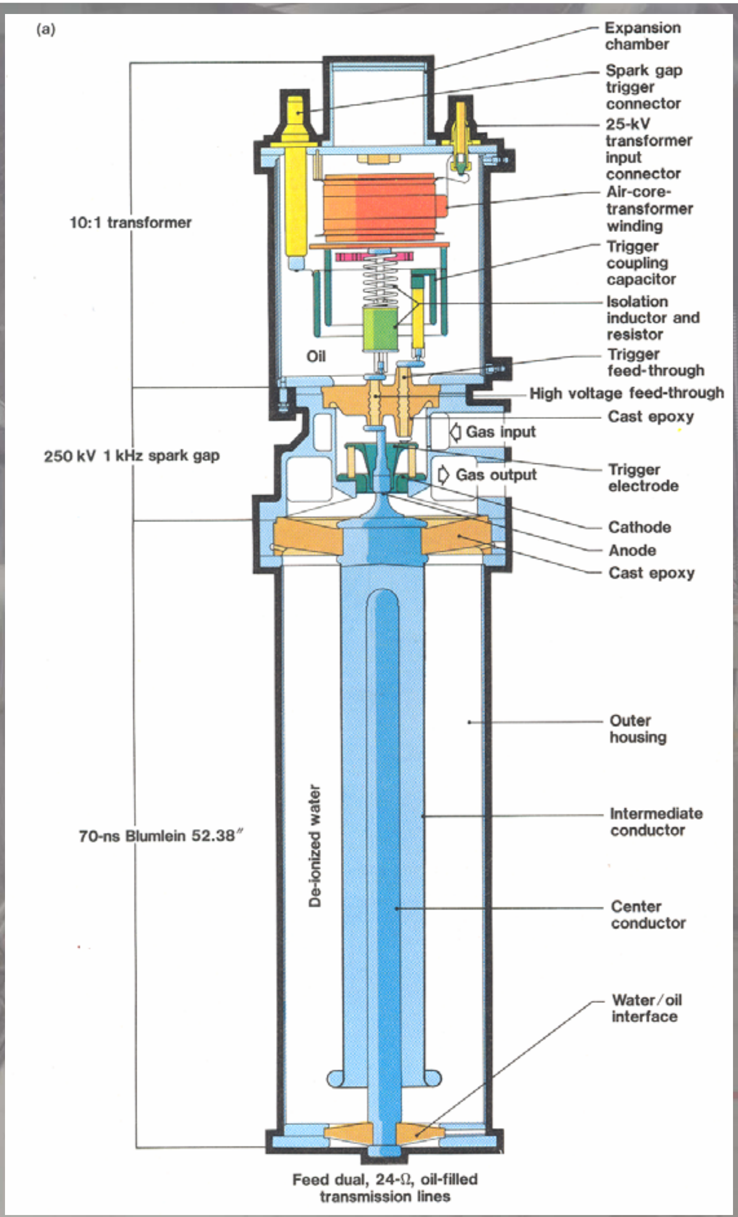




PULSED POWER SYSTEM IS A SUBSTANTIAL PART OF THE ACCELERATOR



PULSED POWER SYSTEM IS A SUBSTANTIAL PART OF THE ACCELERATOR

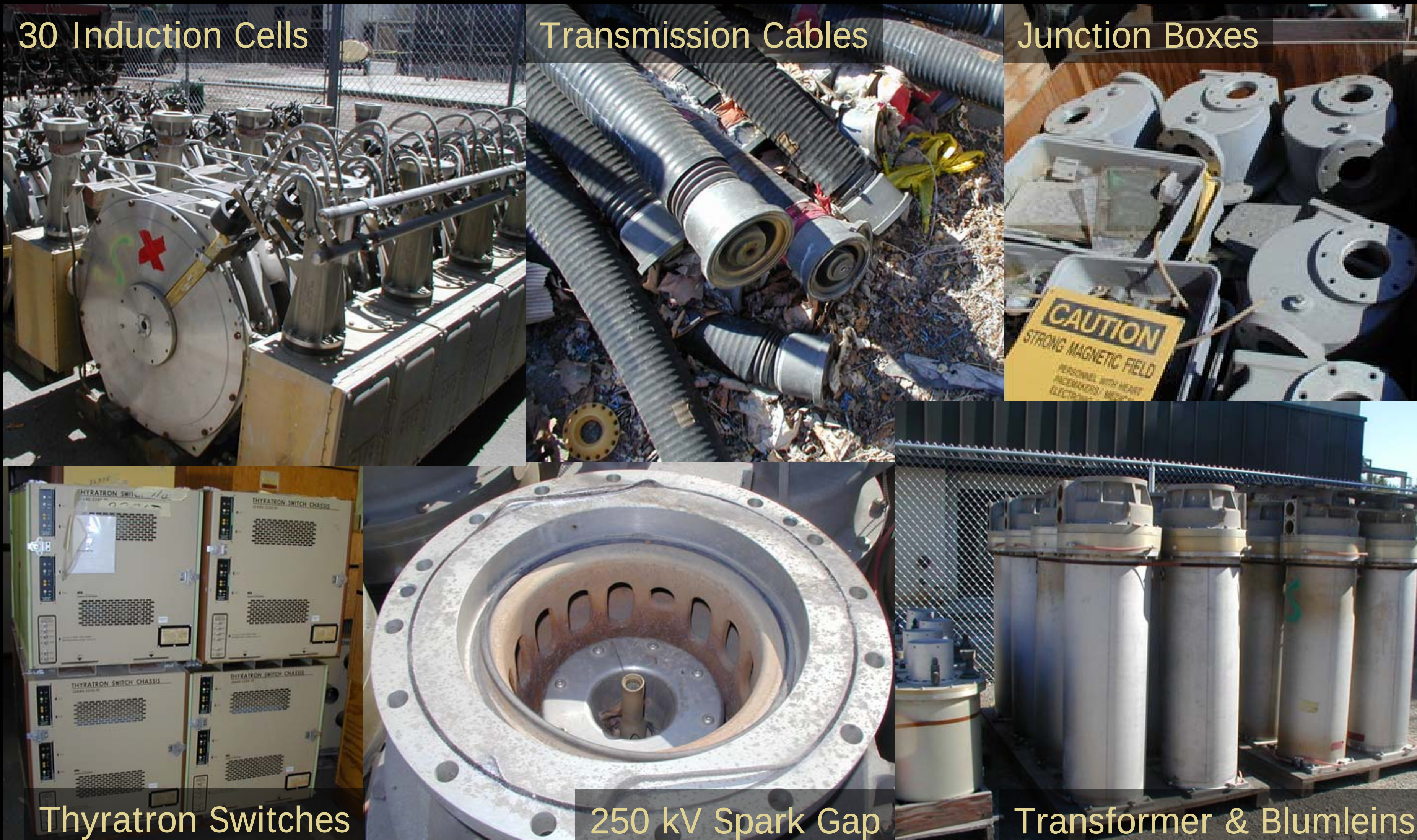


10:1 Step Up Transformer (oil filled)

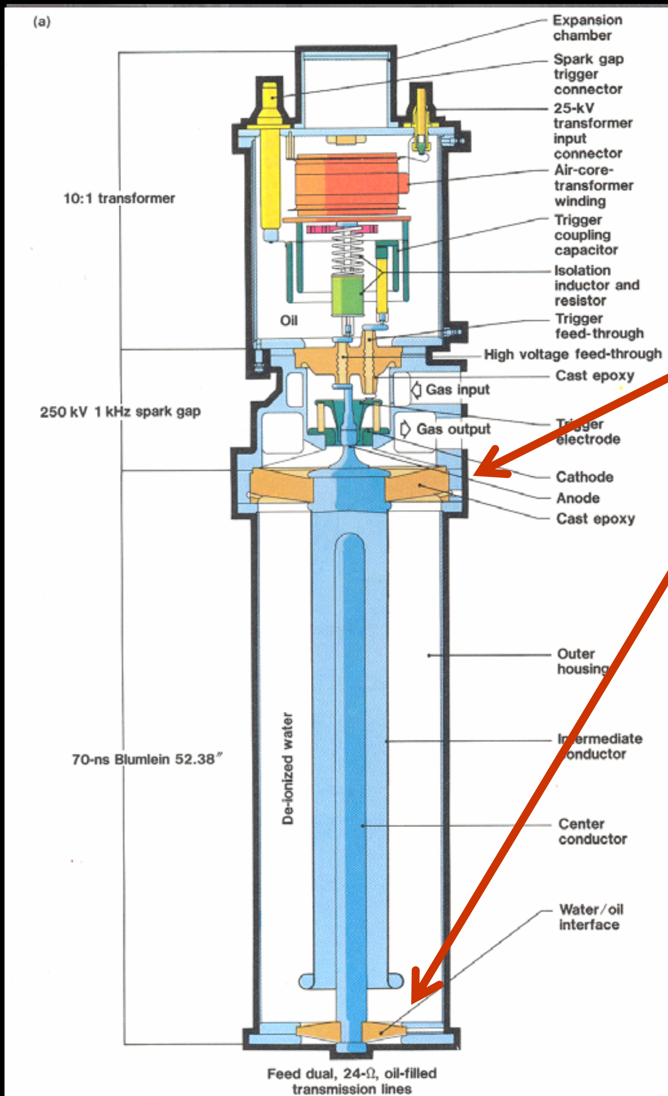
250 kV, 1kHz Spark Gap (SF_6 filled)

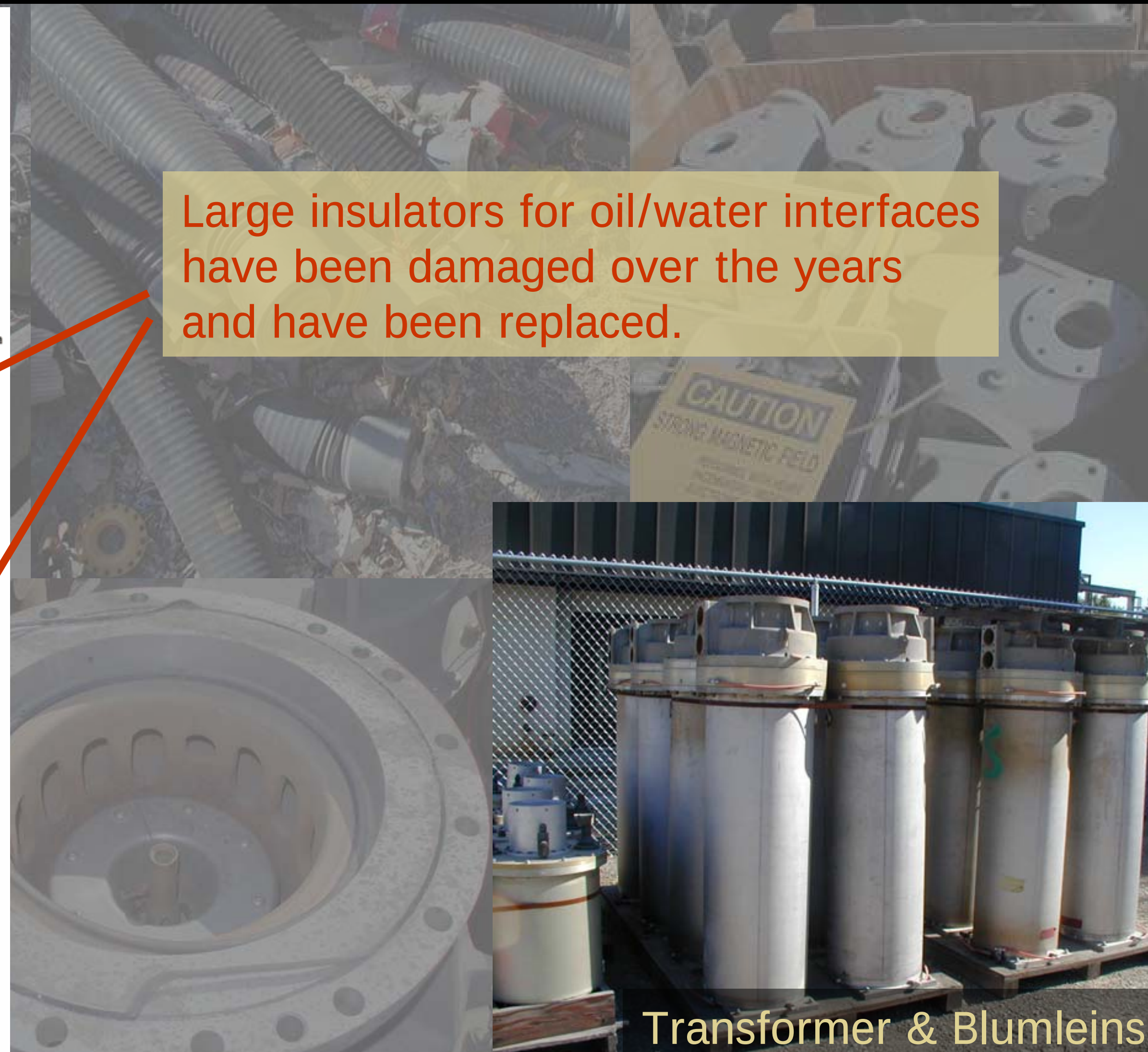
70 ns Blumlein (water filled)

30 ATA INDUCTION CELL UNITS HAVE BEEN SHIPPED TO LBNL



ATA INDUCTION CELLS AVAILABLE





Large insulators for oil/water interfaces have been damaged over the years and have been replaced.

Transformer & Blumleins

ATA INDUCTION CELLS AVAILABLE

Coaxial transmission lines, which are 7 meters long, have been high pressure rinsed and dried with warm nitrogen gas.

ATA INDUCTION CELLS AVAILABLE

All cell components, incl. the 250 kV spark gaps, are in excellent condition. They have been cleaned at the LBNL cleaning facility for re-assembly.